US Army Corps
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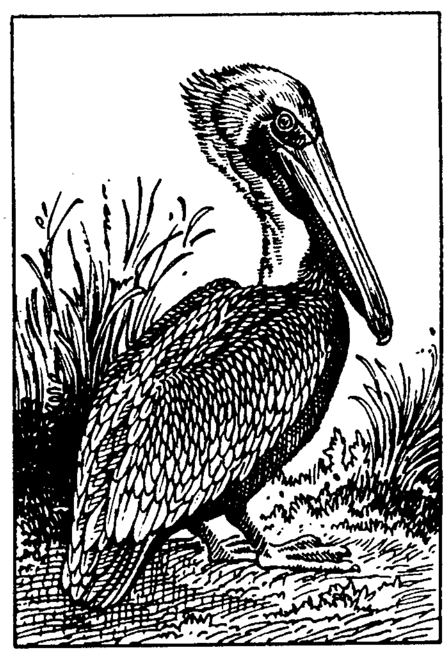
Wetlands Research Program Technical Report WRP-RE-8

Proceedings: National Wetlands Engineering Workshop St. Louis, Missouri, 3-5 August 1993

compiled by J. Craig Fischenich, Cheryl M. Lloyd, Michael R. Palermo



March 1995 – Final Report

The following two letters used as part of the number designating technical reports of research published under the Wetlands Research Program identify the area under which the report was prepared:

	Task		Task
CP	Critical Processes	RE	Restoration & Establishment
DE	Delineation & Evaluation	SM	Stewardship & Management

Wetlands Research Program

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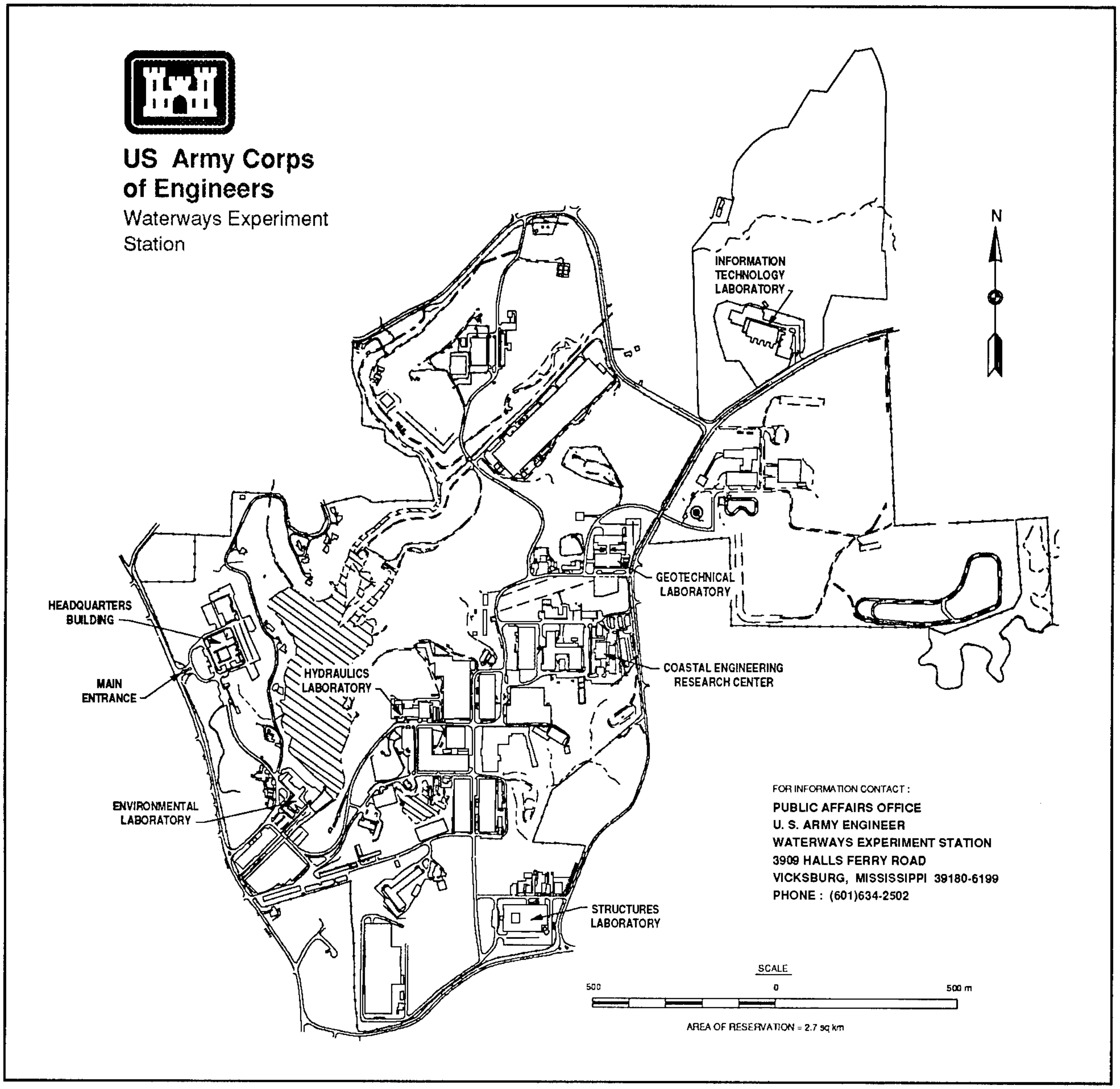
Final report

Prepared for U.S. Army Corps of Engineers
Washington, DC 20314-1000



Waterways Experiment Station Cataloging-in-Publication Data

National Wetlands Engineering Workshop (1993 : St. Louis, Missouri)
Proceedings : National Wetlands Engineering Workshop, St. Louis, Missouri, 3-5 August 1993 / compiled by J. Craig Fischenich, Cheryl M. Lloyd, Michael R. Palermo ; prepared for U.S. Army Corps of Engineers.
450 p. : ill. ; 28 cm. — (Technical report ; WRP-RE-8) (Wetlands Research Program technical report ; WRP-RE-8)
Includes bibliographic references.
1. Wetland conservation — Congresses. 2. Wetlands — United States — Congresses. I. Fischenich, J. Craig. II. Lloyd, Cheryl M. III. Palermo, Michael R. IV. United States. Army. Corps of Engineers. V. U.S. Army Engineer Waterways Experiment Station. VI. Wetlands Research Program (U.S.) VII. Title. VIII. Title: National Wetlands Engineering Workshop proceedings. IX. Series: Wetlands Research Program technical report ; WRP-RE-8. X. Series: Technical report (U.S. Army Engineer Waterways Experiment Station) ; WRP-RE-8.
TA7 W34 no.WRP-RE-8

Contents

Vegetative Techniques Session

Preface

A National Wetlands Engineering Workshop sponsored by the U.S. Army Engineer Waterways Experiment Station (WES) in cooperation with the U.S. Army Engineer District, St. Louis, was held in St. Louis, MO, on 3-5 August 1993. The workshop was authorized by Headquarters, U.S. Army Corps of Engineers (HQUSACE), as part of the restoration and establishment task area for the Wetlands Research Program (WRP), under Work Unit #32760, Techniques, Structures, and Equipment for Wetlands Restoration and Establishment, for which Dr. Michael R. Palermo was the Technical Manager. Mr. Pete Juhle was the WRP Technical Monitor for this workshop.

Mr. Dave Mathis (CERD-C) was the R&D Coordinator at the Directorate of Research and Development, HQUSACE. Dr. William L. Klesch (CECW-PO) served as the WRP Technical Monitor's Representative; Dr. Russell F. Theriot, WES, was the Wetlands Program Manager. Dr. Mary E. Landin was the Task Area Manager.

The purpose of the workshop was to provide a forum for an exchange of information on engineering techniques for wetlands restoration/enhancement projects. The WES individuals who coordinated and managed the workshop were Dr. Michael R. Palermo, EL, Environmental Engineering Division (EED), Special Projects Branch, Mr. Elba A. Dardeau, Jr., and Ms. Cheryl M. Lloyd, both of EL, EED, Engineering Applications Branch (EAB), and Mr. Owen Dutt, Chief of Operations, St. Louis District. Dr. Palermo, Ms. Lloyd, and Mr. J. Craig Fischenich, EL, EED, EAB, compiled and edited this proceedings report.

The preparations for the workshop and preparation of these proceedings were under the general supervision of Dr. Raymond L. Montgomery, Chief, EED, and Dr. John W. Keeley, Director, Environmental Laboratory.

Dr. Robert W. Whalin was Director of WES at the time of the workshop and during preparation of these proceedings. COL Bruce K. Howard, EN, was Commander.

This report should be cited as follows:

Fischenich, J. C., Lloyd, C. M., and Palermo, M. R., ed. (1995). "Proceedings: National Wetlands Engineering Workshop, 3-5 August 1993, St. Louis, Missouri," Technical Report WRP-RE-8, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

1 Introduction

Under its Wetlands Research Program (WRP), the U.S. Army Corps of Engineers is developing improved methods for wetlands restoration and establishment. Wetlands Engineering is emerging as a new and vital aspect of these efforts.

The objective of the National Wetlands Engineering Workshop was to provide a forum for an exchange of information on engineering techniques for wetlands restoration/enhancement projects. Having over two hundred persons interested in Wetlands Engineering in the workshop setting provided an excellent opportunity to obtain input for the contents of a Wetlands Engineering Handbook to be published as a part of the WRP.

Over fifty papers were presented by representatives from government, private consulting firms, and academia. This diversity provided a wide variety of ideas and information. The papers are published as submitted by the authors with only the format being edited to conform to this report style. The papers are presented in the order in which they were given during the workshop. The participants also chose one of seven breakout groups based on their area of interest which met together for two hours each. WES personnel who served as session chairs provided summaries of their sessions which are included in this report.

2 Proceedings Papers

The Role of Technology and Engineering in Wetland Restoration and Creation, Mary C. Landin, PhD,[1] U.S. Army Engineer Waterways Experiment Station Vicksburg, MS

Introduction

Since the 1930's, many millions of acres of wetlands have been restored, created, enhanced, and/or managed by various public agencies such as the U.S. Army Corps of Engineers, the U.S. Fish and Wildlife Service, the USDA Soil Conservation Service and Forest Service, and state Departments of Natural Resources, and by private organizations such as Ducks Unlimited, National Audubon Society, and The Nature Conservancy. In early years, each agency and office often acted independently of others, but are now coming together to share scientific and engineering expertise and experience. Each organization is also searching for ways to address the national problem of wetland loss, and the national goal of no net loss of wetlands. In fact, most are seeking ways to accomplish a net gain of wetlands acres using effective technology and engineering.

Technical information on engineering structures, wetland-friendly equipment, methodologies (including computer data bases), and techniques has been developed under various research programs and hands-on management by the above organizations. Each organization has also published or otherwise made publicly available technical information regarding wetland restoration and creation (Environmental Laboratory 1978, 1986; Federal Highway Administration 1990; Kusler and Kentula 1989; Landin 1992a, 1992b, 1992c; Landin et al. 1989, 1993; Landin and Smith 1982; Soots and Landin 1978; U.S. Army Corps of Engineers 1985, 1989a, 1989b; USDA Soil Conservation Service 1992). Engineering examples included in these publications are geotextiles, protective aquatic-interactive structures, beneficial uses of dredged material, sediment diversion and construction modifications, hydrology and elevational modification technology, flow-altering gates and structures, bioengineering, and numerous others.

In addition to the on-going work of federal and state agencies and private organizations, the National Academy of Sciences tasked two committees of scientists and engineers to identify and examine wetland restoration, protection, and creation technology, one in freshwater systems (National Research Council 1992) with the other focusing on coastal systems (National Research Council, 1994 in press).

Success is defined as achieving the stated goals and objectives of any wetland restoration or creation project, based on agreed-upon replacement values

[1] The author manages the U.S. Army Corps of Engineers Wetlands Research Program task area on wetland restoration, protection, and establishment, Vicksburg, Mississippi 39180-6199.

of the lost or degraded resource. To successfully accomplish wetland restoration and creation, engineers, scientists, and managers must use their expertise and experience in multi-disciplinary efforts that include coordination, communication, cooperation, and often, cost- and work-sharing (Landin 1992a, National Research Council 1994, in press).

The Role of the Corps of Engineers

The U.S. Army Corps of Engineers has restored, created, protected, and/or managed several hundreds of thousands of acres of wetlands since the early 1970's. These wetlands resulted from Corps project activities, and included: (1) lands acquired and restored as wetlands for mitigation of Corps projects; (2) degraded wetlands surrounding Corps projects that were restored and are now managed; (3) wetlands created or restored using dredged material beneficially; (4) greentree reservoirs and moist soil units in association with Corps projects; (5) shoreline wetlands built on Corps reservoir projects; and (6) joint interagency wetland projects in which the Corps was an active partner.

Most Corps wetland restoration and creation projects were developed with primary functions of shoreline and sediment stabilization, erosion control, and fish and wildlife habitats as objectives. Other functions addressed in various Corps wetland projects include water quality improvement, recreational values, contaminant stabilization, and cultural resources. The Corps has found that there are four essential technical factors required for achieving success:

a. Correct hydrology or elevation (stable water supply).

b. Suitable soil/substrate for biotic success.

c. Protection from wind, wave, and wake energies.

d. Correct plant species and propagule selection and installation.

Some examples of selected Corps wetland projects are given in Table 1.

The Corps' multiple mission responsibilities of navigation, flood control, wetland regulation and protection, and national defense give it numerous opportunities to carry out wetland restoration and creation, always in conjunction with other federal and state agencies, and project partners and sponsors, and usually with local citizens groups. Because of these projects, the Corps has developed expertise in both engineering and environmental technology for accomplishing successful wetlands work, as well as developed a common sense approach to restoration procedures (Landin 1992a).

All of the techniques discussed in following sections are part of the tools and techniques available for use with the procedural chart shown in Figure 1. Table 2 provides further specific information from the procedural chart. The approach to successful restoration and creation requires the use of a

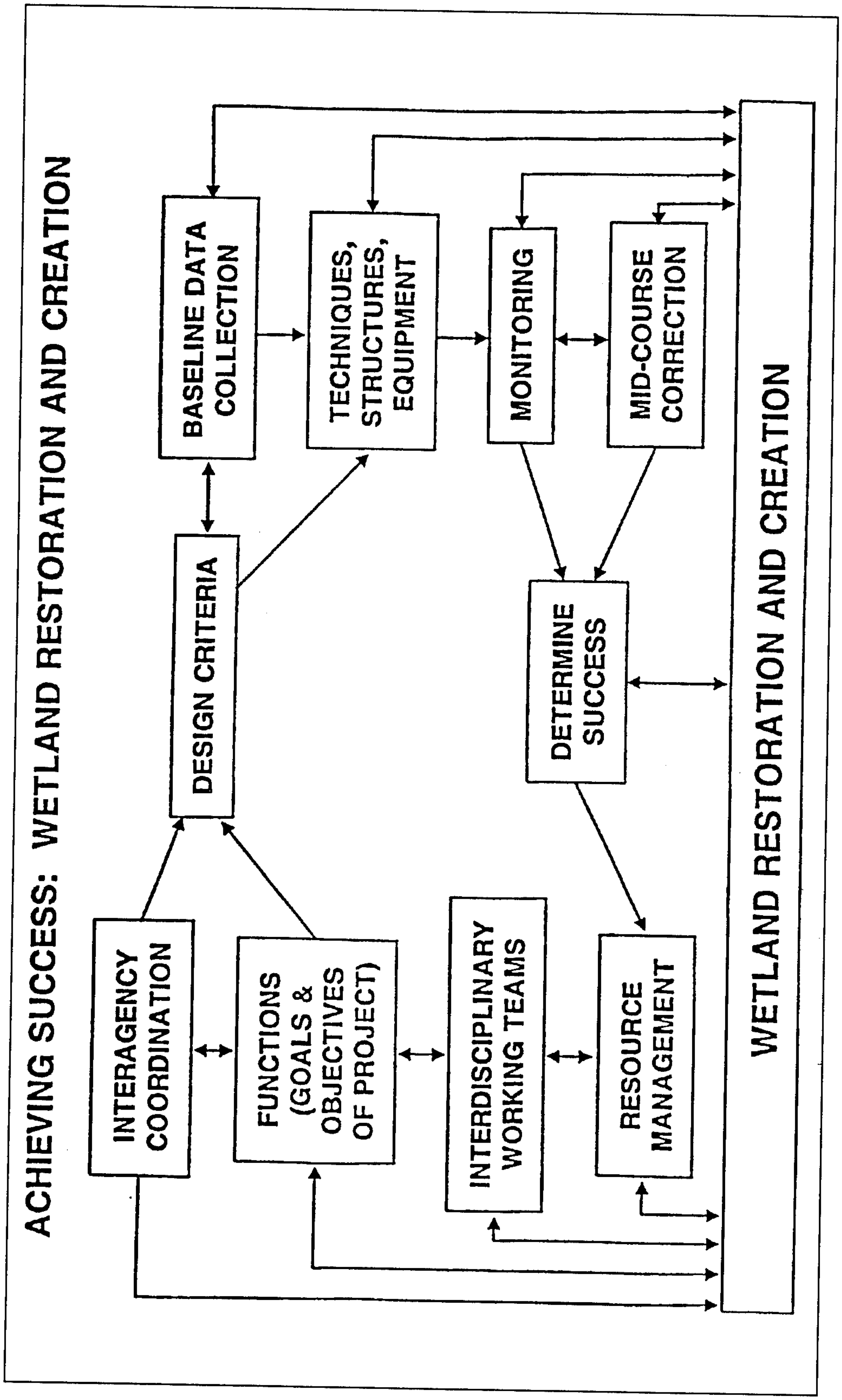
Table 1
Examples of Large and Small U.S. Army Corps of Engineers Wetland Restoration and Creation Projects

Project	Acres	Owner
Pointe Mouillee, Western Lake Erie, MI	4,600	Michigan DNR[1]
Tennessee-Tombigbee Waterway TN, MS, AL	160,400[2]	Miss. & La. DNR FWS[3]
Lake George, Yazoo Basin, MS	9,000	Mississippi DNR
Tensas Basin, Louisiana	10,000+	FWS
Delta National Forest, Yazoo Basin, MS	2,000+	U.S. Forest Service
Gaillard Island, Mobile Bay, AL	1,300	Ala. State Docks
Southwest Pass, Lower Mississippi River, LA	8,000+	State of La.
Weaver Bottoms, Upper Mississippi River, MN	5,000	FWS
Riverlands, Middle Miss. River, Missouri/Illinois	5,000+	Corps
Snake River, Jackson Hole, WY	3,000+	State of Wyoming
Kenilworth Marsh, Anacostia River, Washington, DC	50+	Nat. Park Serv.
Miller Sands Island, Lower Columbia River, OR	135	FWS
Jetty Island, Puget Sound, WA	50+	Port of Everett
Sonoma Baylands, San Francisco Bay, CA	400+	Calif. Coastal Comm.
San Joaquin River wetlands, CA	35	State of Calif.
Eastern Neck, Chesapeake Bay, MD	7	FWS
Galilee Sanctuary, Rhode Island	50+	State of RI

[1] Department of Natural Resources.
[2] Habitats primarily wetlands; also some open water, uplands.
[3] U.S. Fish and Wildlife Service.

multidisciplinary technical team, with interagency coordination (sometimes an agency long-term technical working group), development of practical goals and objectives, baseline data requirements to determine what has been lost and what is to be restored, responsible designs and construction, a monitoring program, and establishment of long-term management responsibilities. Wetland engineering step-wise procedures have been developed by Palermo (1992), and are being refined by multi-disciplinary teams working in the Corps Wetlands Research Program (WRP). They have tested many of the techniques on Corps wetland project sites.

Monitoring is necessary to collect baseline data prior to, during, and following project construction; to document wetland chronology and actions; to use monitoring measurements to determine success rates; and to justify conducting similar wetland projects at future sites (Landin 1992a, 1992b). Long-term management responsibilities must be determined for new wetlands because



ACHIEVING SUCCESS: WETLAND RESTORATION AND CREATION
BASELINE DATA COLLECTION
TECHNIQUES, STRUCTURES, EQUIPMENT
MONITORING
MID-COURSE CORRECTION
DESIGN CRITERIA
DETERMINE SUCCESS
INTERAGENCY COORDINATION
FUNCTIONS (GOALS & OBJECTIVES OF PROJECT)
INTERDISCIPLINARY WORKING TEAMS
RESOURCE MANAGEMENT
WETLAND RESTORATION AND CREATION

Figure 1.

Table 2
Critical Factors for Wetland Restoration, Protection, and Establishment

Goals and Objectives
Identified impacts (functions to be restored, place in landscape)
Regional resource needs
Overall project objective(s)
Consensus among partners/sponsors
Cost-effectiveness
Maximizing success (predictability, flexibility, measurability, achievability)
Low-maintenance requirements
Economy of scale and importance
Wetland Design
Project goals and objectives
Consensus of partners/sponsors
Requirements to meet functional restoration or replacement
Site specific needs
Baseline data
Good science and engineering
Interdisciplinary team approach
Implementation and Construction
Project goals and objectives
Consensus of partners/sponsors
Good science and engineering
Correct hydrology using channel, water, elevational, and/or structural manipulation
Correct soils/substrate using available hydric and/or top soils, seed banks, and soil amendments
Manipulation of energy systems if necessary, through wind, wave, and wake protection
Correct plant selection, propagule handling, storage & placement
Careful application and enforcement of contract and design specifications
Performance Monitoring and Measurements
Project goals and objectives
Consensus of partners/sponsors
Baseline data (pre-, during, post-project)
Need to document techniques, on-site changes, chronology
Justification for application of similar techniques to future wetland restoration/creation
Prove to doubting world that restoration can be accomplished
Comparison to natural, similar wetland systems
Accepted and/or standardized sampling & measurement techniques
Maintenance and Management
Monitoring findings and results
Mid-course correction needs
Original project goals and objectives
Responsibility requirements of permit applicants or constructing agency
Long-term plans, needs, and strategies

they can fail if not maintained or managed, especially in early years. There are many reasons private wetland mitigation projects fail, usually related to poor location, design, and implementation; the public track record is much better in this regard. New wetlands can also fail because no system was put into place to accomplish maintenance, or to carry out any needed mid-course corrections (Landin 1992a).

Geotextile Tubing Applications

Americans have used geotextiles in conjunction with dike construction for many years; Europeans have also used woven geotextiles for a technique called geotubes that has now been tested on a number of wetland sites in the United States (Fowler and Sprague 1993). A geotube can be constructed to be any desired width, length, and height, and is either sewn together in the factory or on-site. It can be made of either tightly woven or non-woven materials to accomplish different purposes. Geotubes typically have one or more small cylindrical openings on the top to be filled from a 6- to 8-inch hydraulic dredge pipe. All geotubes are filled on-site because they are too heavy and unwieldy to move once filled.

Early versions of such materials were used at wetland sites built in Galveston Bay, TX, in 1973 to protect from a 26- mile wind fetch and in Core Sound, NC, in 1979 to build two wildlife nesting islands fringed with planted saltmarsh. These were 10 x 4 x 3 ft, filled with small hydraulic dredges with sand, and stacked to form breakwaters in the configuration desired for wetland protection. In the 1980's, 50 x 3 x 3 ft geotubes were used to protect newly planted seagrass beds, with varying success. Smaller geotubes also were tested in that same time period. By the 1990's, geotubes were being designed and tested for wetlands and for dike repair that were custom-made to accommodate the project. Non-woven geotubes are two layers thick and filled with water; the resulting breakwaters are considered temporary, to be removed once the project has stabilized. These were tested and used successfully at Kenilworth Marsh in Washington, DC in 1992-93 (Figure 2) (Landin and Patin 1993).

Woven geotubes have now been refined to hold fine- textured material as well as sand, a very important improvement. Typically, many wetland projects are in silts or clays, and in the past such material oozed through woven geotextiles. Better fabric construction and texture allows fine-grained sediments to be layered into the geotubes, where it consolidates to densely-packed mud. The Corps has tested these successfully in Mobile Bay, Chesapeake Bay (Figure 3), the lower Mississippi River (Louisiana), and two locations in the Texas Intercoastal Waterway (Chasten et al. 1993, Fowler and Sprague 1993). In Mobile Bay, the geotubes were used for dike repair. In other locations, wetlands were planted behind the geotubes.

The use of such flexible fabrics have added a new dimension to wetland stabilization technology. Geotubes can be built and filled to the exact contour and configuration needed for the wetland. The largest tested to date have been 500 x 20 x 10 ft; however, they can be: (1) designed to be larger or smaller, (2) stacked and layered, (3) form rings to be filled for an island creation, (4) used detached from the shoreline, and (5) sewn to allow high and low spots after filling to better accommodate intertidal flow. The Corps is currently planning a number of other geotube wetland projects. Resource agency response has been very positive, and the U.S. Fish and Wildlife Service (USFWS) and the State of Maryland are cost-sharing several of these projects

Figure 2. Water-filled, non-woven geotube at Kenilworth Marsh, Washington, DC, that temporarily stabilized material until the freshwater intertidal marsh was established

in Chesapeake Bay, including Aberdeen Proving Ground shorelines, Poplar Island, and Barren Island.

Innovative Breakwaters and Bioengineering

Other innovative breakwaters tested by the Corps include detached riprap designs (usually 100 ft of riprap spaced with 100 ft of open water) that can be positioned parallel to, at an angle to, or perpendicular to a coastal, lake, or reservoir shoreline (Figure 4). They can also be placed in an alternating, staggered design in high wave energy or frontal energy situations; placement using this design was found to trap more sediment for marsh protection in coastal Louisiana than a design using a single row of detached riprap breakwaters (Dr. B. J. Good, 1992, Louisiana Coastal Restoration Division, Baton Rouge, LA). Location and placement depends upon current movement, sediment type, project objectives, and wave/wind energy requiring dissipation. Riprap can also be used adjacent to eroding shorelines, with slope gradation behind it which is planted with typical streambank or slope vegetation. It should be noted that riprap can cost as much as 10 times more than geotubes and typical bioengineering techniques.

Figure 3. Sediment-filled, single-layer goetube at Eastern Neck National Wildlife Refuge, Chesapeake Bay, Maryland, that was filled in place as a permanent low-cost breakwater prior to fill placement and planting

Bioengineering is the use of traditional engineering techniques coupled with wetland and shoreline plantings. Bioengineering also typically uses less hard structures and focuses on use of biodegradable erosion control matting, removable structures or features such as floating tire breakwaters. Plantings are typically reinforced with closer spaced-plant, or plants enclosed in burlap tubes, or biodegradable pots, or bundled together as live cuttings. Living fences made from driven double-rowed wooden stakes filled with cuttings, plant material bundles which are buried in the substrate, brush mattresses, and fences made of Christmas trees which trap sediment are just four of the bioengineering techniques that have been tested by the Corps in both reservoirs and on the Gulf coast (Figure 5) (Allen 1990, 1992).

Low-Cost, Low-Maintenance Design and Construction

Because public wetland projects tend to be underfunded beyond project construction, it is extremely important to design and build wetlands that are low-tech, low-cost, and that require little maintenance to remain viable. A wetland that is designed to routinely require manpower to provide water to the wetland, to regulate water levels, and to mow, prune, and otherwise manage vegetation is very labor intensive and requires funding in each year's budget.

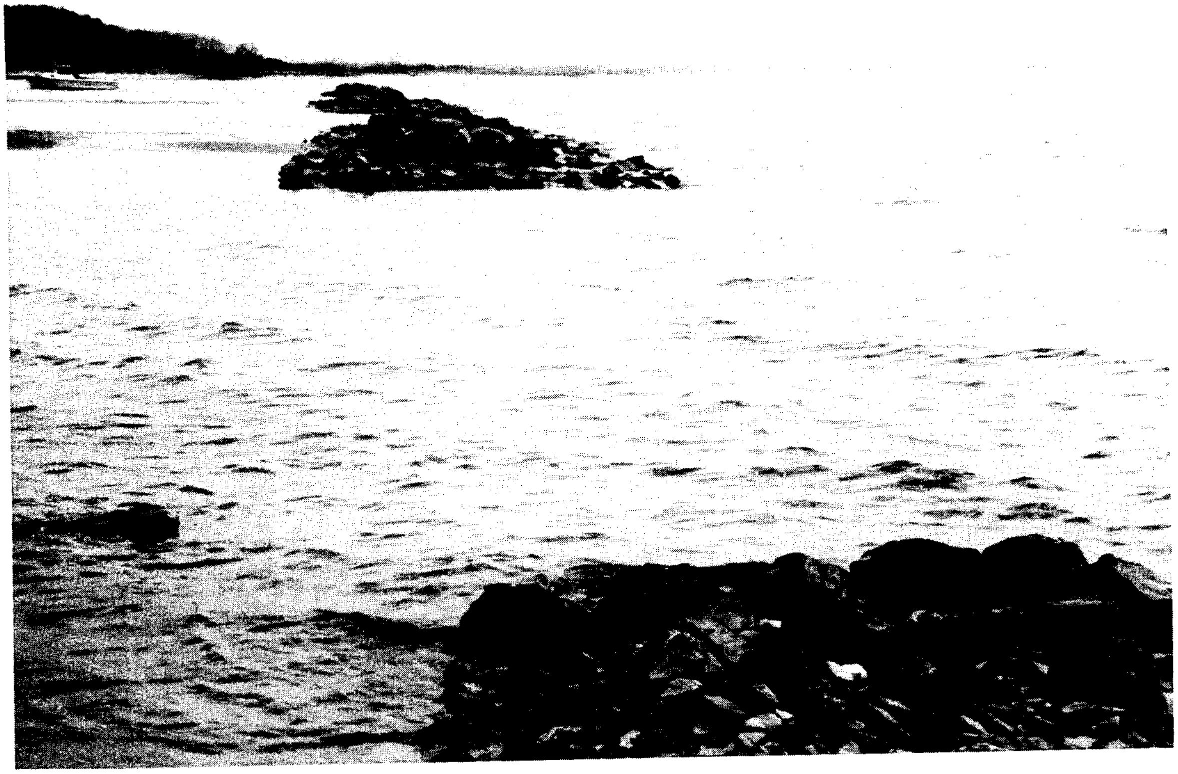


Figure 4. A series of permanent detached riprap breakwaters were installed at Eastern Neck National Wildlife Refuge as part of the overall protection and stabilization design; geotubes extended beyond the riprap

Therefore, Corps wetland projects stress use of native vegetation, having a permanent natural water source (or a well-built low-maintenance impoundment structure), allowing natural colonization of vegetation where possible, and as little earth-moving as possible using traditional methods. It is much less expensive and more efficient, for example, to restore wetland elevations with bottom sediments using a hydraulic dredge than by trucking large quantities of upland fill into the project site. The Corps has used dredged material to restore wetland elevations using hydraulically placement many times; examples include seven wetlands in the San Francisco Bay system, several sites in Chesapeake Bay, and the coastal marshes of Louisiana (U.S. Army Corps of Engineers 1985, Landin et al. 1989). It is also more likely to be successful, because wetland seed banks exist in fine- textured bottom sediments (Environmental Laboratory 1986).

Plant Materials and Propagation

Plant species and materials are integral components of successful restoration and creation projects. Through literature searches, laboratory, greenhouse, and field tests using various wetland species under controlled fertilizer, soil, and propagule treatments, the Corps has developed lists of plant species suitable

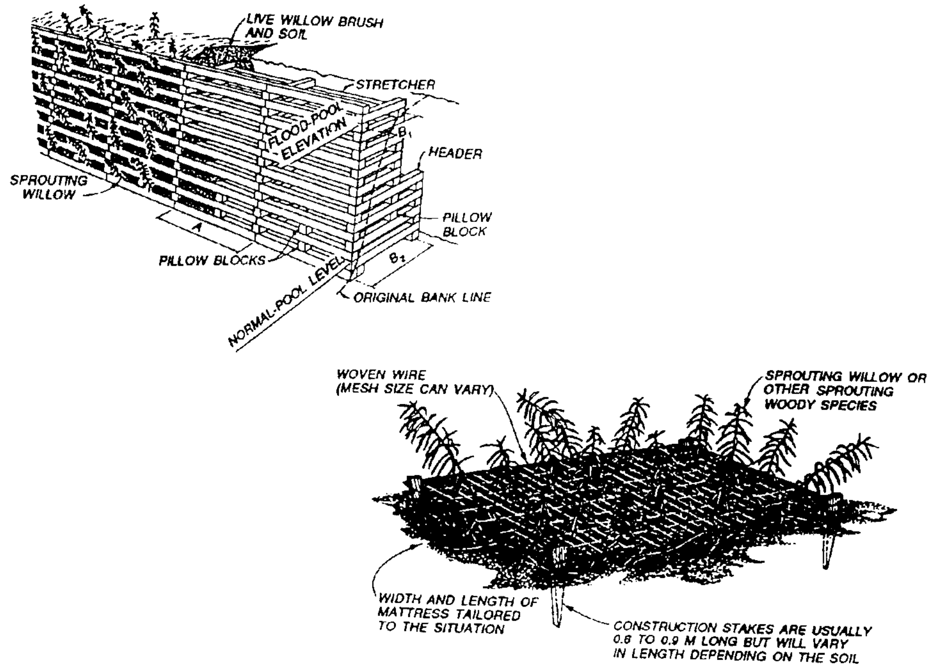


Figure 5. Schematics of bioengineering techniques used to stabilize streambanks and shorelines (from Allen 1992)

for wetland restoration and creation (Allen 1992; Allen and Klimas 1986; Environmental Laboratory 1978, 1986; Landin 1978; U.S. Army Corps of Engineers 1985). These lists are currently being refined to suit a wide range of wetland restoration and creation conditions as part of WRP. The Corps uses its botanist, wildlife and fisheries biologist, and ecologist team members to determine what plant species are best to meet project objectives and how they should be planted and maintained. As many as 30 different species may be planted on Corps projects requiring diverse wetlands, using various propagule types to insure project success.

It should be noted that the simpler the planting requirements and the smaller the size of the propagule, the less expensive planting will be. However, plant materials are generally one of the least costly components of a wetland project; soil/sediment transport, land acquisition, protective breakwaters, and earth-moving in site preparation are the most costly components.

Monitoring

Monitoring is goal/objective driven; in wetlands restoration and creation, goals and objectives are determined based on functions and values lost, degraded, and/or needed. Monitoring is necessary to collect baseline information, to document activities and chronology of the project, and document success or failure and the need for mid-course correction, and to justify building a

similar wetland project in the future. The identification and use of statistically-valid measurements for each component (e.g.; fish, invertebrates, wildlife, water quality, soils, structural integrity, elevations) sets a standard for the success of the project that should be a consensus determination by all technical team members. These in turn will help establish success criteria for the project (Landin 1992a, 1992b). The Corps is actively working with other agencies to develop interagency monitoring standards and success criteria for different types of wetlands, although this is still several years away from completion.

As an example of a Corps wetland project based on the above information, Kenilworth Marsh's goals and objectives were (1) to restore freshwater intertidal wetlands in a degraded lake system; (2) to place the Anacostia River flood-control maintenance material beneficially; (3) to enhance the recreational and educational aspects of Kenilworth; and (4) to use low-cost, low-maintenance techniques for accomplishing the restoration project. Engineering and environmental designs and construction were based on those four points; monitoring focuses on both engineering and environmental integrity, as well as how well the site has recovered for educational canoe trips, birding, and other passive recreational activities. Success criteria include full vegetation cover of planted species after one growing season with continued survival and reproduction, self-maintenance of new wetland elevations, and self-maintenance of newly-cut canoe trails. Data from Kenilworth are being used to design and build a similar wetland at Kingman Lake, also in the Anacostia River (Landin and Patin 1993).

Summary

Wetland restoration and creation in Corps projects is multi-disciplinary and in cooperation and partnership with other agencies. A common sense approach and procedure has been developed that covers the basic requirements for achieving success. Engineering and environmental technology for wetlands has been identified, tested, refined, and applied by the Corps for over two decades. Geotextiles, non-traditional breakwaters, bioengineering, plant material requirements, and monitoring needs and logic were presented. Numerous examples of successful Corps wetlands are already constructed, with other wetland projects in planning and coordination stages, ready for 1994 construction.

Acknowledgements

Wetland projects discussed in this paper are cooperative, partnered efforts between the Corps and a number of other federal and state agencies. Information presented herein was obtained from research conducted under the Dredging Operations Technical Support, Dredging Research Program, and the Wetlands Research Program of the US Army Corps of Engineers by the

Waterways Experiment Station. Permission was granted by the Chief of Engineers to publish.

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Planning for Wetlands Water Quality, Eric A. Stiles,[1] Bureau of Reclamation, Denver, Colorado

Introduction

Wetlands and water quality are both topics of tremendous scope. Wetlands are transitional in terms of ecosystem succession and across the spatial boundaries of aquatic and terrestrial environments. Due to their position in the landscape, wetlands are directly exposed to land and water use practices. Water quality is a pervasive issue since it can reflect internal wetland process properties as well as the implications of adjunct watershed conditions. Management of water resources comprises a third comprehensive topic. The interrelated aspects of these topics may be critical in planning wetland-related actions. Experience has shown that features neglected in planning tend to be shaped by default, as a consequence of other actions, rather than by design.

Effective planning is essential to achieve desirable results whether actions are directed to protect or enhance wetland ecosystems, to integrate wetlands into watershed management plans, or to utilize the water purification properties of wetlands. Although water quality is widely recognized as an important function in wetlands, even the term "wetlands water quality" can lead to discussion regarding what is defined, how prevalent mechanisms are influenced, and what steps are appropriate to address different situations encountered in practice.

Major obstacles faced in planning are attributed in part to the inherent diversity of wetland conditions and complex interactions that affect water quality. Distinct design criteria are rare and where available are often incomplete or confined to specialized circumstances. Entirely different sets of legal statutes, regulations, and procedures are applicable to actions concerning wetlands, water quality, and water resource operations. Sound policies and effective guidance can facilitate technical development, which in turn provides direction toward creating consistent administrative procedures and better policies to direct future actions. It appears that methods to differentiate between classes of wetland water quality conditions could help organize information and address some of the critical information gaps.

The following sections describe a framework for evaluating the predominant water quality characteristics that are applicable in planning for wetland related actions. Water quality constituents are grouped according to the prevalent behavior that is exhibited in common wetland systems. Fundamental transformation mechanisms and process factors are examined to reveal trends useful in planning and design. The objective is to demonstrate an organizational procedure that can be used to identify critical issues, uncertainties, and risks such that reasonable decisions can be made without the benefit

[1] The views expressed herein are those of the author, and do not necessarily represent the policies or opinions of the U.S. Bureau of Reclamation.

of perfect information. The approach is qualitative and purposely flexible in keeping with the goal of providing immediate guidance to facilitate project planning, while contributing to the long-term advancement of improved wetlands engineering techniques and design criteria.

Wetlands and Water Resources

By nature, many conventional water resource activities intersect wetland-related issues under a variety of circumstances. New construction may require protection of existing wetlands or mitigation of unavoidable impacts; irrigation operations may involve planning to dispose of drainwater or to utilize return flows where appropriate; opportunities can arise to enhance the aquatic and wildlife habitat value of water facilities; and in some instances, wetland functions can be applied specifically to alter water quality within the wetland or in the downstream waters.

Interactions between wetlands, water quality, and water resources are typically moderated in situations where water is plentiful. Individual wetland or water resource actions may not interfere with other uses and water quality impacts can be diluted or assimilated if water supplies are sufficient. Conversely, in arid areas water supplies are more limited and these issues become inseparable.

In many arid regions of the western United States, water quality problems are accentuated by evaporation effects, hydrologic extremes, and unique geologic conditions, which in turn can affect the chemical composition or alter normal assimilation processes. Aquatic ecosystems tend to be small and widely dispersed, and as a result, they can provide habitat that is critical to sustain local wildlife populations (Gibbs 1993). Arid ecosystems are established slowly, in response to the natural hydrologic regime, yet situations without external water demands are rare. Western water is tapped for human use and distributed through extensive facilities with operations governed by statutes and contractual arrangements that are ingrained in the historical development of the west. Scarce water places emphasis on conjunctive approaches to sustain water and ecosystem resources.

Wetland Science and Policy Trends

Progress in wetlands science and technological development can be attributed in part to efforts undertaken to resolve specific issues encountered in individual wetlands projects. Examples and selected references concerning the major types of wetland activities include: delineation of wetlands (Adamus et. al. 1987, FICWD 1989, Tiner 1993), creation and restoration (Schneller-McDonald 1990, Kusler and Kentula eds. 1990, Hammer 1992), constructed wetland treatment systems (EPA 1988, Hammer ed. 1989, WPCF 1990, Reed and Brown 1992, Moshiri ed. 1993), wetlands integrated in watershed manage-

ment (NRC 1992, Olson ed. 1993), and wetland management to provide habitat for designated species (Fredrickson and Taylor 1982).

The predominant functions recognized in wetlands have been delineated in several sources (e.g., Marble 1990). Most reports identify 8 to 13 functions, with the principle difference being the level of detail applied. Common to all lists is recognition of the importance of wildlife values and water quality functions in some form. This trait is supported by the bulk of wetland projects which tend to fall into two categories corresponding to these functions. Projects concerning wetlands creation and restoration focus on replacing wildlife habitat functions (Sifneos et. al. 1992), while constructed wetland projects are primarily oriented toward water treatment, with wildlife values incorporated as ancillary benefits. Studies are more rare that traverse these areas to assess the wildlife values and risks associated with constructed wetlands, or conversely to correlate incidental water quality attributes of natural or restored wetlands with performance measured under the more controlled conditions produced in constructed systems.

Divergent areas of development are also evident in two prominent areas of policy which appear to have contradictory objectives. Provisions of the Clean Water Act (CWA, as amended 1987) and water quality standards for wetlands (EPA 1990) are intended to alleviate contamination of wetland systems. At the same time, other sections of the CWA contain guidance pertaining to the use of wetlands as management practices to intercept non-point pollution, and several manuals have been produced to guide the design of aquatic systems specifically applied to treat wastewater (e.g., EPA 1988, and others). The distinction between these seemingly contradictory goals lies in the definition of "Waters of the United States." This distinction probably has more historical and administrative significance today than relevance to known characteristics of wetlands. From a scientific standpoint, the conflict is largely a matter of degree. It depends on the magnitude of pollutant and the nature of any potential hazard risks involved.

Various tactics have been employed to examine functional relationships in wetland ecosystems. Considerable water quality process information has been derived from constructed wetlands where the hydrologic regime is controlled, while less information is available pertaining to water quality attributes in a watershed setting. Correlation with natural systems is hindered by the tremendous range of variables possible that affect water quality characteristics spatially or over time. Local conditions can appear unique, even when underlying features coincide with other situations. Water and land use practices may obscure functional boundaries while the affects of certain actions are not visible for several years. In rare instances demonstration projects have been designed and built to establish specific test arrangements. This can allow more direct investigation of the performance corresponding with design features. Application of these results to other applied wetland projects is tentative, although it is likely to be more definitive than trying to isolate the confounding influences found in natural wetland systems.

Recognition of the dynamic nature of many ecosystem processes has led to the emergence of "ecological engineering" (Mitsch 1992). In a recent article describing ecological engineering, the author states: "[it] involves the design of this natural environment using quantitative approaches and basing our approaches on basic science. It is technology with the primary tool being self-designing ecosystems" (Mitsch 1993). This indicates that design features that are consistent ecosystem constraints and natural succession will tend to be more self-sustaining. To achieve specific results the engineer must correctly interpret interrelationships, anticipate the direction of succession, and implement elements effectively on site. Distinct criteria to accomplish these feats rely heavily on technical development that remains incomplete to date. Meanwhile, even without essential design criteria wetland ecosystems are continuously modified by all types of human activities.

A natural tendency may be to handle uncertainty by ignoring unknown factors, or simply waiting until firm information is available. Neither course is appropriate without evaluating potential consequences and methods possible to compensate for critical factors. Recently, terms such as; "integrated watershed management," "holistic planning," and "adaptive management" (e.g., NRLC 1992) have been used to describe approaches to sustain resource uses, and address complex issues where fundamental properties and interrelationships may be unclear. This is not to say that policies and administrative procedures become so loose that they lack substance. It does suggest that tiered or hierarchical approaches may be useful to discriminate actions in proportion to the level of uncertainty and risk involved including areas of public health concern, irreversible environmental damage, or methods that are clearly not practical or cost effective.

Water Quality Framework

Water quality represents the collective influence of all phases that interact with water. We know that wetland processes are collectively related to hydrologic influences, geomorphology, and interaction with soils, vegetative materials, and other biota. Of particular interest are the factors that control oxygen transport, production, respiration, oxidation-reduction, nutrient cycling, carbon dynamics, precipitation, and sedimentation. Spatial and temporal variations, transformation kinetics, and the long-term succession can also be important. Over time better knowledge of explicit process relationships in wetlands will contribute to improved design criteria, and conversely, proper follow-up evaluations of projects can help to delineate the practical attributes that control process functions.

A framework to organize wetlands water quality information is shown in Figure 1. The center of the diagram indicates the need to gain a better understanding of the fundamental relationships to develop design criteria. The figure illustrates how performance relationships are continuously refined through an iterative process. The bottom half of the figure indicates case studies of wetland sites are used to measure actual system performance in an attempt to

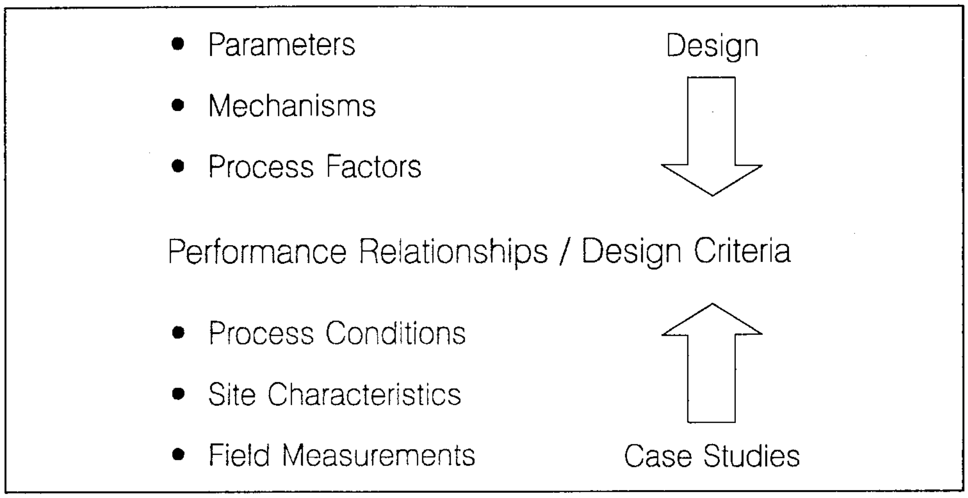

Figure 1. Wetlands Water Quality Framework

derive empirical correlations. On the upper part of the figure, existing information regarding characteristics of water quality parameters, wetland transformation mechanisms, and process factors are applied in design to induce desired attributes. When projects are subsequently evaluated, the information can be valuable toward better understanding of the basic performance relationships. This completes the cycle that refines underlying principles and eventually contributes to assembling more accurate design criteria.

The remainder of the discussion here focuses on the design side, where wetland water quality attributes are compiled as a systematic approach taken toward design planning. Water quality constituents, transformation mechanisms, and process factors form the essential "what, where, and how much" questions in the wetland water quality framework. The information presented in this section is primarily adapted from principles of limnology and aquatic chemistry (e.g., Wetzel 1983, Stumm and Morgan 1981), transformations in wetlands (Kadlec 1981), as well as selected references on constructed wetlands cited previously. The concepts described are biased to "emergent marsh" classes of wetlands (Cowardin 1979). The qualitative attributes described assume healthy well established marsh conditions. The intent is to review prevalent trends, with the precaution that site constraints and the influences of connected terrestrial and aquatic systems must always be considered in practice.

Water quality parameters

The first step in the water quality framework is to differentiate classes of common constituents that characterize water quality. For these purposes, constituents are defined by the ordinary physical, chemical, and biological parameters that are measured in water. The prevalent behavior of parameters in wetlands and any associated problems or risks are of particular interest here. Parameters are grouped according to the relative transformation effectiveness,

uncertainties concerning mechanisms, and potential hazard posed in each case. The following operational groups of wetland water quality parameters are suggested:

Group 1 - BOD, Nitrogen, Suspended Solids. Wetlands tend to be effective in reducing these types of constituents providing the flow velocities and water retention times are adequate and total load rates are not excessive. These parameters are often the primary basis for design of constructed wetlands.

Biochemical Oxygen Demand (BOD) is broadly defined here to include labile organic material that is easily degraded by aerobic microbial processes in wetlands. Removal of BOD from the water column can be fairly efficient depending on the loading and oxygen content. Wetlands also exhibit a high assimilative capacity for nitrogen depending on its initial form, loading rates, carbon sources, and oxygen status. Nitrogen can be completely eliminated by microbial nitrification and denitrification. To achieve these processes both aerobic and anaerobic conditions must be present to some extent.

Suspended particulate matter is removed through physical settling. Efficiency is generally very high due to slow flow velocities and filtering effects through the vegetative biomass. Sedimentation can be a critical factor since high sediment loads can accumulate rapidly to fill the effective wetland water volume. The capacity of a system to absorb sediment and digest organic solids can indicate whether special consideration is warranted to handle suspended solids.

Group 2 - Phosphorus, Major Metals, Microbes. While wetlands often exhibit some ability to remove these constituents from the water column. The overall effectiveness is less certain and depends more on specific mechanisms and site conditions. Key factors in this group include the efficiency of processes and the stability of major end products. (Sulfur could also be included in this group).

Phosphorus is separated from the common term "nutrients" due to the complex mechanisms that can influence phosphorus. Elimination of phosphorus relies on stabilization in sediments, metabolic uptake combined with biomass harvesting, or downstream export. In this group "metals" refers to common non-toxic types of metallic elements found in water. Metals tend to be stabilized in sediments if the sediment surface layers remain oxidized and mixing is low. The ultimate fate of phosphorus and many metals depends on how they are sequestered, redistributed or subjected to biological cycling.

Microbes are placed in this group primarily because natural die-off can often be effective, but the persistence of individual varieties in relation to site-related variables is not well known. Additional assessment of health hazards is warranted if pathogenic forms of bacteria or viruses are present.

Group 3 - Toxic Trace Elements, Synthetic Organics. This group is distinct due to the greater toxicity risks and very specific nature of possible environmental interactions. The group is comprised of unique elements and compounds that are affected by entirely different mechanisms in wetlands. Some trace elements can be immobilized in sediments, and certain organic compounds will decay into less harmful forms. Specialized studies are advised where these types of constituents are present. Bioaccumulation, and evaporative concentration are often important issues associated with the parameters of this group.

Group 4 - Resistant Organic Carbon (as DOC), TDS. These constituents are not normally reduced in wetlands, in fact they tend to accumulate or become more concentrated in water flowing through wetlands. Elevated levels of Dissolved Organic Carbon (DOC) or Total Dissolved Solids (TDS) may or may not indicate problem conditions in wetlands. Implications are more likely to depend on the adjunct uses of water from a wetland system. The effects on ecosystem structure, microbial rate functions, and interactions with other substances can also be important. Actual site conditions must be considered in detail where inflow loading is high or the wetland exhibits extended retention times.

Wetland mechanisms

Mechanisms refer to the process transformations that occur to alter the quality of water in a wetland system. An extraordinary array of mechanisms is possible in a typical marsh, and each constituent might be affected by one or more mechanism. Fundamental mechanisms include physical effects, biological transformations, and chemical reactions that can take into account nearly every combination of events. Some sources further differentiate mechanisms into processes such as filtration, adsorption, chemical precipitation, sedimentation, photolysis, direct uptake, and microbial decay (Stowell et. al. 1980). These descriptive reviews of mechanisms identify the types of processes, but do not explain how mechanisms are induced, enhanced, or inhibited in actual wetland systems.

A common marsh can exhibit tremendous structural diversity across the spatial dimensions and as a vertical gradient in the water column. As a result, the underlying relationships between wetland elements (geomorphology, hydrology, vegetation, soils), and the resulting water quality are difficult to ascertain. Collective attributes are more easily examined and provide valuable information regarding the net product of simultaneous interactions. The sequence of local separate processes can also be important. Some wetland systems have defined compartments, or regions of local isolation that represent functional mesocosms. These composite attributes are useful because they embody the features that can be modified in practice. Mechanisms can be evaluated accordingly. Certain types of relationships are readily apparent. For example; sedimentation induced by lower flow velocities, or the filtration effects of plant biomass. Biological mechanisms are often more complicated

and may be subject to different multiple factors such as retention time, oxygen, and substrate surface area.

Aggregate Process Trends. General characteristics regarding removal of certain constituents from the water column in a simple wetland are shown in Figure 2. For these purposes, a "simple wetland" refers to a consistent emergent marsh wetland which operates as a flow-through system. In this figure, the flow path lies along the horizontal axis with the inlet at zero. Units indicate relative distance or equivalent downstream travel time. The vertical axis represents the relative changes in constituent concentration in the water column as a proportion of inflow levels. Trend lines shown are adapted from constructed wetland projects combined with established characteristics associated with each constituent.

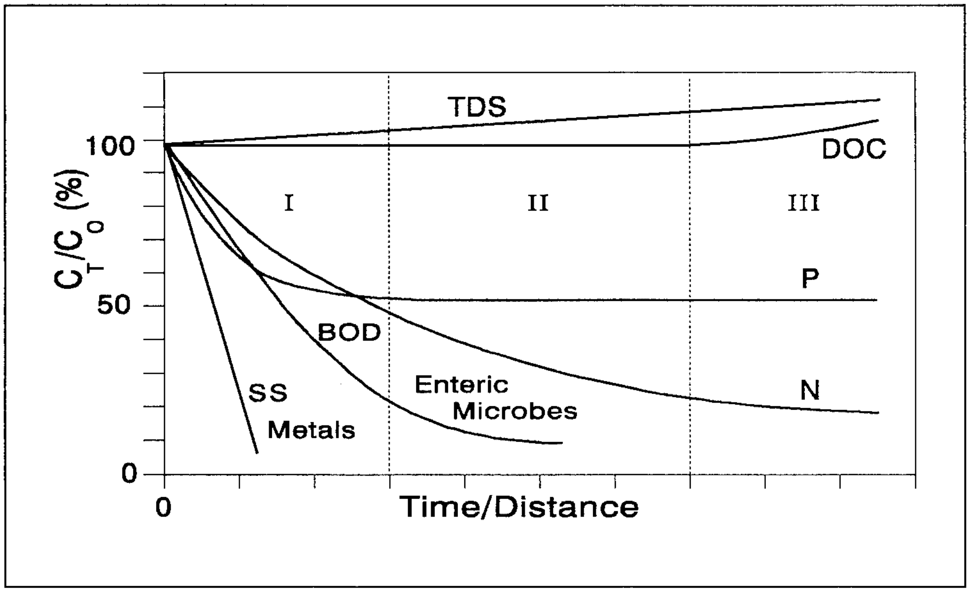

Figure 2. Wetland Process Trend

Note that the curve lines shown are entirely conceptual. They are intended to illustrate the relative shape and general direction of mechanism process trends. The exact position and values of these curves are not derived from measured data, and therefore could vary substantially from any actual wetland ecosystem.

The straight line for suspended solids indicates linear sedimentation immediately downstream of the wetland inlet. Many metals behave similarly, due to chemical precipitation and adsorption to particulate matter. BOD and enteric microbes tend to exhibit first-order decay properties with fairly efficient end removal. Nitrogen is shown with a similar decay curve, only the shape is elongated to indicate the relatively longer retention required for multiple-stage bacterial processes. The shape of this curve also varies according to the initial form of nitrogen present. Phosphorus tends to exhibit initial drop, but the

efficiency levels out to reflect internal cycling that frequently limits the net removal. DOC and TDS both show no effect, or a net increase that could characterize the general behavior associated with larger systems that exhibit a long hydraulic retention time

Operational Mechanisms. The predominant wetland water quality relationships represent "operational mechanisms," that is, the net effects or prevalent behavior of constituents in aquatic systems. Some operational mechanisms take place over the limits of a wetland complex while others are more confined to local areas. Three distinct regions are apparent as indicated by numerals in Figure 2:

I. Front end sedimentation, precipitation, filtration are prevalent
II. Biological transformations with variable net dynamic rate functions
III. Production, accumulation, concentration in large, slower systems

Operational mechanisms are particularly amenable to application in design with the precaution that aggregate trends do not eliminate the inherent risks associated with certain constituents. Many mechanisms that affect water quality will occur to some extent in all areas of a wetlands, but they are enhanced or inhibited in local mesocosms. In a flow-through system, the net effects on water quality will reflect the collective processes, whether they occur concurrently or separate. Information regarding how configuration, vegetation patterns, and sequential compartments can effect associated mesocosm processes could greatly improve wetland design.

These concepts may be applicable to evaluation of the conditions that influence water quality in natural systems, as well as in design of features for wetlands creation, restoration, or constructed wetland projects. For example, the overall dimensions of wetland areas are directly related to hydraulic retention time. The configuration can effect the hydrodynamic properties of a wetland. In practice, sedimentation processes might be isolated from other areas in a wetland system, or vegetation patterns altered to change water routing and flow velocities.

Creation and restoration projects tend to be designed simply to fit within existing landscape features. In a watershed setting, these operational mechanisms could be reviewed with respect to site conditions that determine the feasibility of creating wetlands. Therefore, flexibility is imparted in the application of operational mechanisms. Modest review may be appropriate early in planning, while concepts are applied intensively in design to encourage desirable characteristics.

Process factors

The third component of the water quality framework consists of variables that control processes, and the implications of any wetland-induced transformations. Process factors are modifiers to the general behavior of parameter

groups and mechanisms previously described. In this discussion, the term "system" could refer to a small localized area within a defined ecosystem, or could comprise an entire wetland complex. Concepts presented remain the same in either case.

Rate and Efficiency. These factors refer to the transformation dynamics occurring in a system. Rate functions in wetlands are analogous to reaction kinetics of pure systems, except they coarsely represent the composite performance characteristics. Rate is used to indicate the change in constituent concentration over time or an equivalent distance downstream. The term "efficiency" indicates the net change in concentration as a percent of the original concentration over a unit area and time. For example, the inflow versus outflow. In effect, the efficiency combines rate functions with the hydrodynamic properties of a system.

Precise algorithms to describe all types of wetland processes are not available to date and may not be practical to pursue given the diversity of wetland conditions possible. Empirical relationships for common constituents have been derived by correlating data from multiple sites, although the variance in these cases is often quite large. Still, any rate limited functions that could effect the continuous or seasonal performance cycles should be considered in planning and design.

Process Variations. A so called "steady-state" condition is prerequisite to define performance rate functions. Considering the complexity in even simple wetland ecosystems, the collective term "homeostasis" may be more accurate. Once the defined static condition is established, significant variations are examined to reveal any potential implications. Process variations can be local or distributed, and can include daily and seasonal trends, or episodic events that alter inflow mass loading for a given constituent or affect internal wetland processes.

Ultimate Conditions. Considering the long-term characteristics of any project is extremely valuable to get an accurate assessment of the potential risks, overall benefits, and uncertainties. This includes the projected design life, tradeoffs between maintenance and retirement, and ultimate conditions that are expected based on what is known about mechanisms and interactions.

The transitional nature of wetlands is manifested by performance characteristics over short periods that are entirely different from long-range future conditions. Unfortunately, post-construction monitoring is uncommon. When factors causing disturbances cannot be determined, evaluating a range of extreme circumstances can give insight to potential consequences. Similarly, an essential part of planning can be to examine the projected implications at critical points in time (and locations) that reflect the major uncertainties and risks.

The effectiveness of a system is related to efficiency, except that it goes one step further to include duration and variability. Performance effectiveness

can thereby describe the end product limitations of a system (or project) taken as a whole, and the ability of a system to tolerate short term disturbances. Effectiveness can be measured with respect to net reduction of constituents over time, the overall value of a given strategy, or the costs of a unit wetland characteristic. In this context, effectiveness includes intangibles that might influence project feasibility.

Planning and Design

The water quality framework provides basic tools that can be applied to evaluate wetland water quality issues prior to planning any wetland actions. In a second tier, the same tools are utilized to evaluate problems and opportunities, and then finally, to prepare detailed design plans. The focus of this section is on the interface between the water quality framework and conventional design procedures for wetland creation, restoration or constructed wetland development projects.

Design elements

Wetlands engineering consists of implementing ecosystem features through design that is applied at a landscape level. To achieve water quality objectives, the design is intensively directed toward features that produce desirable interactions between water, vegetation, and soils. Attributes such as wildlife habitat and public values are generally incorporated as ancillary adjustments to the basic wetland water quality design. Design elements shape the physical configuration and establish the initial conditions in which natural processes will interact to gradually modify the system in the direction of ecosystem succession. Four of the essential design elements are discussed as follows:

Landform. This term describes the physical elevations and shape that comprises a wetland system. Landform is the geomorphology of a site, and as such it is an extremely important aspect. It differs from soils in that it deals with overall contouring rather than local properties, although the geotechnical nature of soils can play a major role in how a site can is manipulated. Landform has a subtle, yet profound effect on wetland characteristics. It establishes the depths and grades that ultimately influence water flow, vegetation patterns, and corresponding habitat attributes. The overall configuration of a wetland system is the primary factor that sets hydraulic parameters resulting from the hydrologic regime.

Water. The essential ingredient to form wet-land is, of course, water. Water provides conveyance and is the media for all wetland transformation processes. Design considerations include defining the predominant hydrologic regime which effects the wetland. In a watershed setting extreme events are frequently just as important as the baseline conditions, especially with respect to constituent loading. The inflow water budget and water quality correlations can be difficult to define.

Normally the water budget is fixed and design is oriented toward water depths, flow rates, retention times and other aspects that control the way water interacts, rather than the supply itself. Water quality can be integrally tied to flow characteristics as well as upstream land use practices and other activities. Groundwater discharge or recharge traits can affect both the water quantity and quality as can evaporation and transpiration effects. In some situations it may be appropriate to control the wetland water supply to isolate inflow at certain times or to operate the supply within water right requirements.

Vegetation. In constructed wetlands, and aquatic treatment systems, vegetation is an essential factor in the water quality performance. Vegetation requirements can play a major role in design to accommodate desired varieties. Plants are often installed at some considerable expense, to encourage uniform growth patterns. In creation and restoration projects, planting is less common, although some "spot" planting and seeding might be done to start preferred varieties. More often, water control is used to encourage growth from the native seed bank, and to manage wetland areas to produce wildlife food crops or eliminate noxious weeds.

Soils. The last design element is often overlooked. The interaction of soils with water quality and other wetland functions may be the least understood aspect in wetland science. Biogeochemistry is especially relevant to wetlands since soil development and sedimentation are major process in wetlands. Although certain aspects pertaining to biological decay, peat formation, and digenesis of soils are known only general information is available regarding how soil conditions should be addresses in design. Other issues include the soil consistency and porosity, organic and mineral composition, water retention properties, surface interactions, and oxygen transfer characteristics. Unfortunately, projects are typically not monitored long enough to make conclusive assessments of soil interactions.

Project planning

The water quality framework is intended to reviewed at key points during project planning and design development stages. Table 1 illustrates how the water quality framework, shown as WQF, is integrated into the design process. It is important to apply the WQF tools early to assess potential implications of projected actions and evaluate water quality prospects. The WQF is then reviewed to discriminate between conceptual design alternatives, and as preliminary design proceeds it is reviewed again with respect to any new facts obtained through site investigations. Finally, the WQF components are used to refine features in preparation of final design plans. The effort applied in review can be adjusted to serve as a quick checklist or become more intensive in response to any problems that arise.

Table 1
Matrix of Design Elements and Development Stages

	WQF	Objectives, Conceptual Design Plans	WQF	Preliminary Design, Site Investigations	WQF	Final Design Engineering	Construction, Establishment	Evaluate Performance
Landform		wetland size, grades, slope, configuration,siting factors		existing site topography, constraints, adaptability		detailed plans for physical features as adapted to site	site earthwork requirements, and other site considerations	does as-built configuration achieve goals, how to modify
Water		quality goals, supply needs, identify water constraints		site hydrology extremes and reliability, water quality		design details to establish water regime and controls	water control structures, and related site water features	water quality improvement and wetland sustainability
Vegetation		water quality relationships, growth rates, habitat value		existing, local, regional types, soil seed bank potential		select plants, plan growth and anticipated succession	wetland plants, site seeding or revegetation as appropriate	spatial patterns plant survival, and succession characteristics
Soils		organic or mineral soils, time required to establish		site soil types, permeability, chemistry, use in construction		determine soil materials, need for liner, other requirements	strip, stockpile to replace, or import soil as required	changes over time produce hydric soils, organic soils
Cost		concept level cost estimate		site-specific cost factors		final engineer cost estimate	record actual costs	evaluate major cost factors

Conclusions

The concepts presented here are not new, they are simply reformulated to suggest methods to guide planning for the water quality properties of wetland systems. The three areas described in the water quality framework are proposed as basic tools useful in project planning. Early review of the representative parameter groups can provide insight into the potential problems, opportunities, risks, and uncertainties that may be important in selecting an approach for further planning. Transformation mechanisms are important as they pertain to the site features in conceptual design plans. Assessment of the ultimate conditions anticipated is essential to evaluate site compatibility and long-term implications in advance of taking any actions involving wetland ecosystem properties.

As wetland engineering emerges as a distinct discipline, it is extraordinarily diverse and interdisciplinary by nature. It is clear that individual project objectives and site-specific conditions can have a marked influence on the nature of any wetlands and, in turn, the induced water quality attributes. The success of wetlands engineering is contingent on planning and design that correctly interprets prevalent characteristics, translates these effectively to set forth the initial morphological conditions and anticipates the course of natural succession.

Water is the common ingredient that flows through wetland ecosystem processes, policies, and institutions to provide for human uses and to sustain ecosystem resources. As human populations continue to grow, greater stress will be placed on water resources, resulting in greater emphasis on conjunctive approaches to manage water for multiple purposes. Advance planning is essential to be able to identify processes that are compatible with water resource constraints, and then assemble design plans that are consistent with the wetland ecosystem tendencies.

An effective framework includes allowances for practical constraints such as varying site conditions and adaptability toward different administrative institutions. An approach based in fundamental principles was selected because it is amenable to hierarchical application. It is flexible in application to different circumstances or simply to guide in compiling information. It is intended to be useful at various stages of planning ranging from formulating design alternatives to preparation of detailed design plans. The underlying theme is that as this framework is refined through use, it will contribute to policies that are consistent with science and technology and thereby allow more coordinated administration of the interrelated issues concerning wetlands, water quality, and management of water resources.

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Wetlands Restoration is Included in Management Measures for New Coastal NPS Programs, Christopher F. Zabawa[1] and John N. Hochheimer[2]

Introduction

The United States has important interests in coastal environments. These interests involve issues such as the protection and restoration of the natural functions of wetlands and riparian areas, and the maintenance of water quality and habitat in rivers, lakes, and estuaries. The environmental impacts on natural resources from increasing numbers of people living in coastal areas are of particular concern. Nearly one-half of the United States population currently resides in coastal areas, and the population living near the United States coast is projected to increase by 60% in the next twenty years. As the population in coastal areas of the United States has increased, there has been a decline in coastal water quality, a loss of wetlands, closures of beaches, and pollution of fisheries (Greenwood, 1990; Morris, 1992).

Pollution in coastal waters of the United States originates from a combination of traditional *point sources* (such as discharges through pipes from sewage treatment plants and industrial facilities), and *nonpoint sources*. Nonpoint source (NPS) pollution is caused by rainfall or snowmelt moving over and through the ground, picking up natural pollutants or those resulting from human activity. Hydrologic modification is also considered to be a form of NPS pollution that adversely affects the physical and biological integrity of surface waters. The distinction between water pollution coming from point sources and nonpoint sources is sometimes subtle, but diffuse nonpoint pollution is presently considered to account for between one-third and two-thirds of the current problems with water quality in surface waters of the United States (USEPA, 1992a).

Separate sections of this paper briefly describe and discuss the national effort in the United States to control NPS pollution, the actions to be taken in accordance with recent Federal legislation to help coastal states address the problem of NPS pollution in coastal waters, and how the new coastal NPS program is related to restoration of wetlands. The purpose of the new coastal NPS program is to implement management measures for nonpoint source pollution by more fully integrating federal, state and local authorities. The intent of the wetlands restoration management measure is to ensure that the nonpoint benefits of restoring wetlands and riparian areas will be considered in all coastal watershed water pollution control activities (USEPA, 1993).

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Background

What is nonpoint source pollution?

Nonpoint source pollution generally results from land runoff, precipitation, atmospheric deposition, drainage, seepage, or hydrologic modification. Coastal nonpoint pollution sources include agriculture, forestry, urban and suburban runoff, construction and development, septic systems, roads, marinas, and hydromodification projects. Technically, the term "nonpoint source" is defined to mean any source of water pollution that does not meet the legal definition of "point source" in § 502(14) of the Clean Water Act (CWA). Although diffuse runoff is generally treated as nonpoint source pollution, runoff that enters and is discharged from conveyances is treated as a point source discharge and hence is subject to the permit requirements of CWA. In contrast, nonpoint sources are not subject to federal permit requirements.

National efforts to control NPS pollution

Diffuse sources of water pollution are harder than traditional point sources to identify, isolate, and control. Since the passage of the Clean Water Act in 1972, EPA and the states have made the greatest progress in reducing pollution of surface waters by issuing permits to point sources, and then inspecting, monitoring, and enforcing those permits to ensure that point sources meet CWA requirements. Point sources are regulated by EPA and the states through the National Pollutant Discharge Elimination System (NPDES) permit program established by § 402 of CWA. Discharges of dredged and fill materials into wetlands have also been regulated by the U.S. Army Corps of Engineers and EPA under § 404 of CWA.

Although pollutant loads from point source discharges have been greatly reduced in the United States, this has not solved all of the Nation's water quality problems. Recent studies and surveys by EPA and by state water quality agencies indicate that the majority of the remaining surface water quality impairments in the United States result from nonpoint source pollution and other nontraditional sources, such as urban storm water discharges and combined sewer overflows (USEPA, 1992 a,b).

NPS Program. In 1987, Congress enacted § 319 of the Clean Water Act, which established a national program to control nonpoint sources of water pollution. Under § 319, states were to assess NPS pollution problems and causes, then develop and implement management programs. Section 319 authorizes EPA to issue grants to states to assist in implementing those programs or portions of programs which have been approved by EPA.

National Estuary Program. EPA also administers the National Estuary Program (NEP) under § 320 of the Clean Water Act. This program currently addresses point and nonpoint pollution in 21 geographically targeted,

high-priority estuaries. In each case, state and regional/local governments develop plans for conservation and management, and recommend priority corrective actions to restore estuarine water quality, fish populations, and other designated uses of the waters.

Pesticides Program. Another program administered by EPA that controls some forms of nonpoint pollution is the pesticides program under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). Among other provisions, this program authorizes EPA to control pesticides that may threaten ground water and surface water. FIFRA provides for the registration of pesticides, for enforceable label requirements which may include maximum rates of pesticide application, for restrictions on pesticide uses, and for classification of pesticides as "restricted use" pesticides (whose use is restricted to certified applicators specially trained to handle toxic chemicals).

Coastal Zone Management Program. The Coastal Zone Management Act of 1972 (CZMA) established a program through NOAA for states and territories to voluntarily develop comprehensive programs to protect and manage coastal resources. To receive Federal approval and implementation funding, states and territories had to demonstrate that they had programs, including enforceable policies, that were sufficiently comprehensive and specific both to regulate land uses, water uses, and coastal development and to resolve conflicts between competing uses. In addition, they had to have the authorities to implement the enforceable policies. There are presently 29 federally approved state and territorial CZM programs. Despite institutional differences, each program must protect and manage important coastal resources, including wetlands, estuaries, beaches, dunes, barrier islands, coral reefs, and fish and wildlife and their habitats. Resource management and protection are accomplished in a number of ways through state laws, regulations, permits, and local plans and zoning ordinances.

CZARA legislation

While water quality protection is integral to the management of many coastal resources, it was not specifically cited as a purpose or policy of the Coastal Zone Management Act of 1972. The Coastal Zone Act Reauthorization Amendments of 1990 (CZARA) charge state CZM programs, as well as state water quality programs, with addressing nonpoint source pollution affecting coastal water quality.

CZARA requires EPA, in consultation with NOAA and other Federal agencies, to prepare and publish guidance specifying "management measures" to restore and protect coastal waters from specific categories of nonpoint source pollution. Management measures are defined as: *economically achievable measures to control the addition of pollutants to coastal waters, which reflect the greatest degree of pollutant reduction achievable through the application of the best available nonpoint pollution control practices, technologies, processes, siting criteria, operating methods, or other alternatives*. The

management measures approach is technology-based, rather than water-quality based. The management measures in the CZARA guidance are based on technical and economic achievability, rather than on cause-and-effect linkages between particular land use activities and particular water quality problems.

The CZARA Management Measures guidance (USEPA, 1993) contains a description of methods and practices, including structural and nonstructural controls that will be effective in reducing nonpoint pollution from several sources. The guidance identifies the types of pollutants that may be controlled by best available technology, and provides quantitative estimates of the pollution reduction effects and costs of the measures. There is also a description of the factors that should be considered in adapting the measures to specific sites or locations. States will have the flexibility to use the illustrative management practices presented in the guidance or other practices that can be shown to meet the requirements of the management measure to develop programs "in conformity" with the various management measures. For all of the management measures, the practices illustrate what EPA has found to represent the types of practices that can be applied to successfully achieve the management measure.

EPA and NOAA have jointly published Program Development and Approval Guidance (NOAA and USEPA, 1993) to explain the basis and process for states to implement the management measures "in conformity" with the technical guidance. This document describes what each state must include in a coastal nonpoint program by July 1995, as well as how NOAA and EPA will review and approve the programs. If a program is not approvable, certain Federal grants to the states must be curtailed beginning in fiscal year 1996.

The guidance focuses on five major categories of nonpoint sources that impair or threaten coastal waters in the United States. The CZARA guidance also contains management measures for wetlands, riparian areas and vegetated treatment systems, including engineered or constructed wetlands.

Agricultural runoff. Coastal waters are affected by NPS pollution resulting from erosion of cropland, from the manure and other wastes produced in confined animal facilities, from the application of nutrients, pesticides, and irrigation water to cropland, and from physical disturbances caused by livestock and equipment, particularly in and along streambanks.

Urban runoff. New development should be planned and designed to protect sensitive ecological areas, minimize land disturbance, and preserve existing stream beds and vegetation. In existing developed areas, buffer strips and engineered or constructed wetlands can be installed to remove sediment and other pollutants before runoff reaches streams and lakes. Roads and bridges should be sited away from sensitive ecosystems.

Silvicultural (forestry) operations. The timing, location, and design of tree harvesting operations, and the construction and maintenance of forest roads, play important roles in the control of NPS pollution to surface waters

from forestry operations. Protecting forest vegetation in streamside management areas can help filter pollutants in runoff from adjacent lands, as well as provide shading which influences the water temperature of streams. The functions of forested wetlands should also be protected, since they offer benefits to water quality and habitat.

Marinas and recreational boating. Because marinas are located at the water's edge, there are a variety of NPS effects associated with flushing of boat basins, with spills from refueling areas, with bilge pumping, and with wastes produced by the cleaning and repair of boats.

Hydromodification. These activities have been separated into three categories: channelization and channel modification, dams, and erosion of shorelines and streambanks. Channelization and channel modification frequently diminish the suitability of instream and streamside habitat for fish and wildlife, and alter instream patterns of water temperature and sediment transport. Hardening of banks, in particular, can increase the speed of movement of NPS pollutants from the upper reaches of watersheds into coastal waters. Dams can affect the hydraulic regime, the quality of surface waters, and the suitability of instream and streamside habitat for fish and wildlife. Shoreline and streambank erosion is a natural process that can have either beneficial or adverse impacts on surface water quality and on the creation and maintenance of coastal habitat. Eroded shoreline sediments help maintain beaches and replenish the substrate in tidal flats and wetlands. However, excessively high sediment loads can also smother submerged aquatic vegetation, cover shellfish beds, fill in riffle pools, and contribute to increased levels of turbidity and nutrients.

Wetlands. The CZARA guidance contains management measures for wetlands because an important function of natural wetlands and riparian areas is the removal of NPS pollutants (e.g., sediment, nitrogen, and phosphorus) from storm water. Wetlands and riparian areas have also been shown to attenuate peak flows from storm events, which protects receiving waters from nonpoint source hydraulic impacts such as channel scour or streambank erosion. Degraded wetlands and riparian areas have been shown to have a decreased ability to remove nonpoint source pollution and abate peak flows. Some degraded wetlands become sources of nonpoint pollution by delivering increased amounts of sediment, nutrients, and other pollutants to receiving waters (USEPA, 1993). The management measures for wetlands are:

a. Protection of wetlands and riparian areas.

b. Restoration of wetlands and riparian areas.

c. Promoting the use of vegetated treatment systems.

The first management measure, protection of wetlands, is intended to be applied by states to protect wetlands from adverse NPS pollution impacts as a component of NPS programs. The measure focuses on the NPS problems in

wetlands, as well as on maintaining the functions of wetlands that are providing NPS pollution abatement. The ecosystem and NPS control functions of wetlands should be protected by a combination of programmatic and structural practices, such as identifying wetland functions, considering wetlands on a landscape scale, developing regulatory and/or nonregulatory programs, and using appropriate pretreatment practices.

The management measure for restoration of wetlands and riparian areas is intended to be applied by states to restore the full range of wetlands and riparian area functions to degraded or destroyed wetlands systems that could serve a significant NPS abatement function. Restoration of wetlands and riparian areas refers to the recovery of a range of functions that existed previously by reestablishing the hydrology, vegetation, and structure characteristics. Practices such as restoring the hydrologic regime, reestablishing native plant species, and planning restoration efforts as a part of naturally occurring ecosystems could be used by states to restore wetlands and riparian areas.

The management measure for vegetated treatment systems promotes the use of engineered treatments such as constructed wetlands and vegetated filter strips where they will serve a significant NPS pollution abatement function. Vegetated treatment systems should be applied where they are practical for treating NPS pollution. Vegetated treatment systems remove sediment and other pollutants from runoff. Practices include properly constructing vegetated treatment systems in areas adjacent to waterbodies that may be subject to sediment or nutrient runoff.

State Coastal NPS Programs

The state coastal nonpoint programs represent an innovative approach to dealing with coastal nonpoint pollution because they build upon state and local authorities and expertise. Implementation of the technology-based management measures in the CZARA Guidance will allow states to concentrate on developing and implementing specific forms of land treatment and other practices that experts agree will effectively reduce NPS pollution. Any implementation problems associated with the CZARA guidance should be addressed as they emerge by Congress as part of its continuing oversight of this new program (Archer, 1991). Success in improving coastal water quality will depend partly on the availability of federal funding to support the planning and program development activities needed to implement the states' coastal NPS programs over the next several years. But the CZARA legislation, together with existing provisions of the Clean Water Act, establish an administrative framework for an effective coastal water quality program (Archer, 1991).

Disclaimer

The views and opinions expressed in this article are those of the authors and do not necessarily reflect the policies of the U.S. Environmental Protection Agency.

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SCS Wetland Restoration and Creation From the National View Point, Donald Woodward, Soil Conservation Service, Washington DC

Introduction

The Soil Conservation Service's (SCS) involvement in wetland restoration and creation includes providing technical and financial assistance to landowners, developing technical materials, and conducting training materials.

Federal Programs

SCS provides technical and financial assistance to the land owners to restore, enhance or create wetlands under a number of Federal Programs. These programs promote wetland conservation. These programs and SCS's involvement are described below.

PL566

Cost-share assistance is available to watershed project sponsors under this program. Sponsors can use the money to acquire wetland easements to perpetuate, restore and enhance the natural capability of wetlands.

Nonstructural measures include the acquisition of wetlands to benefit fish and wildlife resources. Structural measures include storage capacity in reservoirs and water control structures. Marsh and pit development to provide fish pools in marshes and breeding and nesting areas for migratory waterfowl are included.

SCS provides 50 percent cost share for required wetland mitigation areas in a watershed project plan.

Currently 95 small watershed projects completed or under construction have fish and wildlife as a project purpose.

Wetlands reserve program (WRP)

WRP is a voluntary program. It offers landowners a chance to receive payments for restoring and protecting wetlands on their property. WRP was authorized by the 1990 Food, Agricultural, Conservation and Trade Act. The program provides landowners a unique opportunity to retire marginal cropland and receive benefits of having wetlands on their property.

WRP obtains 30-year or perpetual conservation easements from participating landowners. The easement becomes part of the property deed. Future

owners of the property are bound by the same terms and conditions as the present landowner. Landowners apply for enrollment by declaring their intent to participate. Then the landowner obtains an approved wetland reserve plan of operation (WRPO). The landowner then submits a bid for the total amount acceptable for granting the easement.

The average easement payment may not exceed the average fair market value of the same type of agricultural land in the area. The bid may be adjusted to account for the costs for restoration and long term maintenance of the easement area.

The acceptable uses of the land are explained in the approved WRPO. Uses include hunting, fishing, timber harvest, and haying or grazing. Duration and timing of these activities is be agreed upon and approved. Activities may not degrade the wetland functions and value of the land.

The SCS and Fish and Wildlife Service jointly help the landowners develop WRPO plans. Each plan describes intentions and objectives as restoration, landowners' requirements, acceptable practices during and after the restoration.

The Fiscal Year 1992 appropriate bill for USDA provided 46 million dollars for a pilot WRP. It set a maximum enrollment of 50,000 acres. In June 1992, a signup was held in nine states: California, Iowa, Louisiana, Minnesota, Mississippi, Missouri, New York, North Carolina, and Wisconsin.

Owners of 2337 farms submitted intentions to participate for 462,078 acres. By the September 1992 deadline, owners of more than half of the farms submitted bids on 249,059 acres. Final acceptance covered 49,888 acres on 265 farms. Only perpetual conservation easements were accepted for the first Signup.

More than 60 percent of the total acreage will be restored to forested wetlands. Almost half of the acreage lies near publicly or privately managed wetlands.

Water bank program (WBP)

The Water Bank Program is a voluntary program in which land owners set aside wetlands with long term contracts. Under the Water Bank Program, SCS provides technical assistance to land owners to protect, improve or restore eligible wetlands. Assistance involves identifying eligible wetlands, helping to develop the conservation plan required for participation and helping to apply contracted conservation treatment. Landowners in over 200 counties in 15 states have participated in this program.

Water quality incentive program (WQIP)

The Water Quality Incentive Program is a voluntary program. SCS provides technical assistance for reduction of agricultural pollutants. Technical assistance includes conservation practices that address wetland preservation and wildlife habitat improvement. USDA enters into 3-5 year agreements with land owners and operators to develop and implement plans to protect water quality.

Eligible lands include wellhead protection area within 1000 feet of public wells. Areas of shallow Karst topography where sinkholes convey runoff water directly into ground water are included. Critical cropland areas having priority problems resulting from agricultural nonpoint sources of pollution are eligible. Areas where agricultural nonpoint source pollution threatens endanger species habitats are eligible.

Conservation technical assistance (CTA)

SCS offers technical assistance to landowners for the restoration, enhancement and creation of wetlands. SCS helps landowners to develop restoration plans to mitigate wetlands. SCS makes scope and effect determinations for landowners who wish to maintain existing drainage systems. SCS will also make recommendations to landowners who wish to enhance or create wetlands.

Technical Materials

SCS assists the staffs in the field offices by developing technical materials.

Chapter 13, EFH

The SCS in an interdisciplinary effort in 1990 developed a new chapter for the National Engineering Handbook (EFH). The chapter is entitled "Wetland Restoration, Enhancement, or Creation." The chapter is used by the district offices of the SCS. The chapter will be used described by Wayne Talbot and Ron Tuttle. SCS has an engineering job approval authority chart for each person in the field office.

The approval authority is based on the experience and knowledge of the person. The planning and design of wetland restoration assignment are based on the approval authority of the person. The entire job and any part of the job must within the person job approval authority. For example, a person may have the authority to plan and design a wetland of 5 acres in size. If the dike at the lower end of a maximum height 8 ft exceeds the job approval authority of 6 ft of a person, the project is designed by someone else.

Practice standards

The SCS developed a draft practice standard for Wetland Restoration. It establishes the minimum standard for all components of wetland restoration. For example, the standard establishes the minimum length of subsurface tile that is removed or plugged when restoring a wetland. All components of the restoration must meet the standard to receive SCS technical approval.

This standard provides a uniform basis for accepting bids in WRP. It should be noted that scs may not provide all the construction inspection required by the site. The farmer or contractor may be provide some or all the construction inspection.

Computer programs

The SCS is developing field office computer software (FOCS) to plan and design the restoration, enhance and creation of wetlands. FOCS provides the user with tools to determine the volume of runoff and peak flow to determine the storage requirements. The computer program routes the inflow hydrograph through the structure to determine the required dike height, etc. The program develops water balances for the proposed wetland to determine if the proposed water levels are to be maintained.

Standard seeding specifications, operation and maintenance agreement and construction specifications can be developed using the computer program. The program has some graphic capabilities to plot cross section, topographic data, and provide earthwork quantities.

This program is being written in C language so that it can be compiled to operate in both DOS and UNIX. This software is being written to operate on a 386 platform.

SCS requires that training in the use of the computer programs be provided as they are released. This training is in the use of the computer program. In some cases discussions of the technical procedures used to develop the computer programs will be included. SCS provides hot line assistance to its users. The technical procedures in the program are approved for use by the National Discipline Leaders.

The computer program is being Beta tested. The software development is being done at the National Information Software Development Staff in Fort Collins, Colorado. Initially this software will not be available to the public.

Training

The SCS developed a training course for our employees covering the restoration and creation of wetlands. The goal is to provide students with an interdisciplinary overview of wetland restoration.

The course covers the general aspects of site selection, design of components and how the wetland should be maintained. The course includes an 8 hour field trip to view wetland functions and restoration techniques. It also includes a 4 hour exercise on developing a restoration plan. The course is offered by the SCS National Employee Development Center in Fort Worth. It has be held at several locations in the mid west over the last two years. Slots have been maintained for other federal and state agency personnel.

Wetland Conservation Alliance

The Soil Conservation Service is working with the National Association of Conservation Districts to establish a Wetland Conservation Alliance. The purpose of the Alliance to promote the conservation of wetlands by (1) developing and marketing clear and consistent messages that will enhance recognition that wetlands are valuable assets for landowners, (2) leading them to conserve and restore wetlands, (3) providing them with an open from to express their views on improvement of wetland programs, and (4) providing better coordination the available assistance. The Alliance will consist of industry, government, farm and environment organizations.

The Alliance will identify and promote non-regulatory approaches to wetland conservation and restoration that are compatible with landowner objectives and needs.

Conclusions

The Soil Conservation Service is involved in the restoration, enhancement, and creation of wetlands. The SCS provides technical assistance to landowners under the aspects of 5 federal programs. SCS develops technical material used as a guide for the planning and design of restored, enhanced and created wetlands. SCS is developing computer program that can be used in the planning and design of wetlands. SCS has prepared practice standards. SCS is working with the National Association of Conservation District to establish a Wetland Conservation Alliance.

The restoration of wetland restoration on agricultural lands by SCS in 1991 was about 80% of the total effort.

Engineering Field Handbook, Chapter 13 "Wetland Restoration, Enhancement, or Creation" USDA, Soil Conservation Service, Wayne R. Talbot[1] and Ronald W. Tuttle[2]

Introduction

Acknowledging that wetlands are dynamic ecosystems with regional differences, Chapter 13 addresses six major kinds of wetlands: leveed, pothole, floodplain, freshwater, riparian, and depressional. Although many of the techniques presented can be applied to other wetland types, they are excluded from discussion.

Wetland processes and characteristics can be divided into three categories, which are basic to understanding any wetland system. The physical processes include an account of the inflow, storage, and outflow of water from a wetland, commonly referred to as the water budget, and the changes brought about by deposition of sediment. Chemical processes and characteristics include redox potential as a measure of potential electron exchange in the soil, nitrogen cycling, reduced forms of iron and manganese, presence of oxidized sulfur, carbon and phosphorus. Biological includes microbial activities, the critical functions of vegetation and the interdependency of wetlands and many species of animals.

A key approach to planning and design is that wetlands are part of an interconnected landscape of ecosystems, in which humans are an integral part.

Planning and Site Selection

The objectives and goals of any wetland project must be defined in the early stages of the planning process. Chapter 13 identifies 13 functions and values to plan for. Table 13-1 of the chapter describes each function or value and discusses associated interrelationships. It would be easy to single out just one function or value to plan for, but chapter 13 suggests the real challenge is in optimizing multiple wetland functions and values so they are in keeping with resource conditions and the landuser's objectives. This is true at the site scale as well as the larger landscape scale, where an understanding of the ecological consequences of resource management decisions is critical. Landscape ecology offers a means of looking at the landscape in this comprehensive manner. An understanding of how a landscape composed of diverse ecosystems is structured, how it functions, and how it changes, allows issues such as habitat fragmentation and biodiversity to be addressed.

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[2] National Landscape Architect, SCS, Washington, DC.

Data collection is the first phase of site evaluation in planning a wetland project and will vary in intensity to be commensurate with complexity of the project area. Chapter 13 contains a helpful checklist which lists items to be taken into account during the data collection and site evaluation stage of planning. This checklist and related site evaluation results are prerequisite to design of the wetland system.

Design

A wetland designer must consider a number of critical factors including hydrology, soil/geomorphology, hydraulics, structural components, and plant materials. Chapter 13 uses an interdisciplinary approach to accomplish this. Data collection, the hydrologic system, structural components, substrate sealing and vegetation are all discussed in detail.

Once data is collected and the wetland functions and location have been determined, a sufficient number of surveys are needed so that any dikes, water control structures, spillways, vegetation, and other features of the wetland can be designed. A topographic survey is recommended for most sites. It is also recommended that a geotechnical investigation be made, especially if structural components will be used. Table 13-2 lists various soils and their characteristics as they relate to dike construction.

The hydrologic system, as it applies to a wetland, is divided into three sections; the water budget, the hydroperiod and the flow characteristics of wetland system. The water budget ($S/ T = Q - Q$) and its components are discussed in detail. These components are precipitation, storm water runoff, evaporation/transpiration, base flow, ground water, pumped water, tidal flow, storage surface water and stored pure water. The hydroperiod of the wetland, which can be determined from data gathered for the water budget, is the seasonal variability of the inflow, outflow and storage. The flow characteristics of a wetland are covered by an explanation and discussion of the three basic flows found in a wetland. These are Depressional, Riverine and Tidal. Photographs and hydraulic equations for each system are included in Chapter 13.

The structural components of a wetland, that are presented, include (1) Dikes and Levees, (2) Water Control Structures, (3) Drainage, and (4) Ancillary structures. In the Dike and Levee section, a detailed discussion is given on height, settlement allowance, dike materials, cutoff trench, and dike stability. Table 13-6 gives recommended dike dimensions for mineral and organic soils.

The second structural component, Water Control Structures, is often an integral part of a wetland system. Several examples of structures used in a wetland system. Several examples of structures used in a wetland system are shown. The various hydraulic characteristics of a structure, weir flow, orifice flow and full pipe flow are discussed. Tables relating hydraulic head to discharge for weir and orifice flow is included. The use of an emergency

spillway, types of spillway, and recommendations on location and design are included.

The third structural component, Drainage, is often overlooked in the design of a wetland system. One tends to shy away from the word "drainage" when working with wetlands. Drainage blocks and basin drainage are discussed. A table on recommended removal rates for food plots is included.

The fourth structural component is labeled as Ancillary Structures. Examples of such structures are observation platforms, elevated walkways, fencing, islands, and hunting blinds.

There are times during site selection that the designer will need to consider substrate sealing. Chapter 13 addresses this by suggesting methods to reduce the permeability of the soils to a point where the losses become tolerable.

Besides hydrology, the most important part of design that will determine success or failure of a wetland is vegetation. In vegetation design, care should be taken to include plant species that match the wetland objectives and that will perpetuate themselves in the wetland landscape. This section of the chapter covers (1) the factors affecting plant selection, (2) natural colonization, (3) planting, (4) species selection, (5) propagules, (6) time of planting, (7) site preparation, (8) equipment used in planting, (9) plant installation, and (10) nuisance species control. Some of the factors that affect plant selection are water supply, water depth, substrate, topography, water and wind energy, and cost. A detailed discussion of planting and species selection in wooded wetland, and herbaceous wetlands is covered. A flow chart for vegetation design is also provided.

Implementation

Implementation, as discussed in Chapter 13, encompasses all activities necessary to achieve the desired functions and values in the wetland. This manual does not go into detail on developing plans and specifications and contracting procedures. There are other manuals and guides developed by the Soil Conservation Services that cover these topics in detail. Quality Control, Site Construction, and Wetland Soil are discussed under implementation.

Quality Control is the responsibility of everyone involved in a project. Quality Control verifies that all the components of the project comply with the project requirements, standards, specifications and established procedures.

Six subjects are addressed under Site Construction -- (1) dewatering, (2) pollution control, (3) dikes and levees, (4) conduits, (5) pilings and (6) construction equipment. Several suggested methods of dewatering a site are discussed. Pollution control is necessary at a construction site to control erosion and minimize the production of sediment and other pollutants of water and air. Fifteen suggested practices to reduce or control pollution are given.

Implementation of dikes and levees is discussed in detail. Foundation preparation, construction in organic soils, construction of a cutoff trench, and borrow ditch location and construction are also covered. Conduits, pilings and construction equipment are covered in less detail. A table listing some types of equipment used in wetland site is included.

The last two subjects under implementation, Wetland Soils as Sources of Plant Materials and Vegetation give the planner and designer options on ways to establish wetland plants on the site. This ranges from site preparation and planting to transporting wetland topsoil, which includes a source of plant materials, to the site.

Monitoring

Monitoring is necessary to measure wetland success, both in the short and long term. Monitoring should begin during the construction stage so that mid-course correction can be made so that the goals of the wetland can be achieved. The importance of setting baseline condition to establish clear and concise criteria, both quantitative and qualitative, are emphasized in this section. Periodic monitoring can then be compared to the baseline to determine success. A checklist to be used on site visits during periodic monitoring is included in the appendix.

Management

A wetland management plan is required for each restored, enhanced or created wetland. This section of the chapter outlines the general concepts of wetland management for wildlife. The reason for choosing wildlife is that management is that management information is readily available and it is presently the reason many landowners restore, enhance or create wetlands. Management technique for prairie potholes, seasonally flooded impoundments, bottomland hardwoods and greentree reservoirs are covered in detail.

The chapter concludes with a reference list, wetland planning checklist, a site visit checklist, and a glossary of terms. The science of wetland restoration, enhancement, and creation is rapidly evolving and improving. Chapter 13 will periodically be updated to reflect the latest technology. Meanwhile, creativity and an interdisciplinary approach are critical to achieving the quality results sought in wetland restoration, enhancement or creation work.

Wetland Engineering: Current Practice and Research Needs, Donald F. Hayes, Timothy R. Crockett, and Michael T. Arends, Department of Civil Engineering, University of Nebraska - Lincoln, Omaha, NE

Introduction

Interest in wetland restoration, creation, enhancement, and protection projects has increased tremendously in recent years. More engineers are involved with wetlands projects and issues related to wetlands than ever before. Although engineering involvement with wetlands is not new, there has not been a long history of continuously evolving engineering practices as for many other areas. Wetland projects can have significant engineering components and many engineering techniques have been adapted for wetland restoration, enhancement, and creation projects. However, the complexity of wetland ecosystems presents many challenges for the development of general design guidance applicable to a wide variety of wetland systems.

Wetland projects tend to focus on providing specific wetland functions such as groundwater recharge, water quality improvement, fish and wildlife habitat, or recreation. In some cases, design functions are selected because they are especially important to the local or regional ecology and their success or failure is crucial to the ecosystem. In other cases, complete functional replacement of existing or previously existing wetlands may be required as mitigation for wetland losses due to construction activity or previous neglect. Regardless of the purpose, origin, or goals of your wetland project, the availability of well established engineering design guidance and techniques increase the chances for success. The purpose of this study was to identify sources of available engineering design guidance and construction techniques applicable to wetlands projects, assess the general state of current engineering practice related to wetlands, and identify areas which need additional research.

Wetland Hydrology

Hydrology is the common link between all wetland functions and processes regardless of the wetland type or its location. Hydrology controls wetland characteristics such as water and nutrient availability, soil conditions, water depths, water chemistry, flow conditions, and vegetation. In turn, each of these characteristics affects the functions provided by a wetland. While hydrologic characteristics vary widely between wetlands, they determine their success or failure whether large or small wetlands and regardless of the local topography and geography. Despite the obvious diversity between wetland types such as southern swamps, prairie potholes, coastal marshes, and mountain pools, similar hydrologic conditions usually provide similar wetland functions.

The numerous studies of wetland hydrology attest to its importance. However, most hydrologic studies of wetlands have been site specific and, thus, have limited application to other wetland sites. Some authors have attempted to generalize the hydrologic requirements for a successful wetland. O'Brien (1988), Kusler and Kentula (1990), Marble (1992), and Hammer (1992) present fundamentally sound descriptions of wetland hydrology and desirable hydrologic conditions. While each author presents a slightly different viewpoint, they all agree on the inseparable tie between hydrologic conditions and wetland functions and processes. The key to a successful wetland is the establishment of hydrologic conditions which promote the functions and processes desired for the wetland project.

Water budgets or balances have been used for decades (if not centuries) to evaluate the hydrologic characteristics of man-made water retention structures such as ponds, lakes, and reservoirs. Water budgets simply account for anticipated inflows such as streams, channels, and rainfall runoff, outflows such as releases and groundwater seepage, and losses such as evaporation and transpiration. Differences between inflows, outflows, and losses yield changes in storage within the water body. An accurate and reliable water budget is critical for assessing wetland hydrology under a variety of conditions such as flood, drought, or even normal conditions. While the general concept is no different from a lake, pond, or reservoir, it can be much more complicated to develop a useful water budget for a wetland. The transition zone between upland and aquatic areas where wetlands exist is a region of change. Small changes in water levels can result in major changes in groundwater seepage, evapotranspiration, and water depths on wetland vegetation. While small changes in groundwater seepage rates and evapotranspiration may be negligible in large water bodies, they may dramatically affect the small storage capacity of most wetlands and alter the conditions required for establishing desirable vegetation and habitat. Thus, an accurate water budget is crucial to establishing hydrologic conditions conducive to a successful wetland. Carter, et al (1978) provides a concise summation of conducting a water budget for a wetland.

The most apparent engineering aspect of restoration or creation projects is the manipulation of the natural hydrology to provide hydrologic conditions which foster the wetlands' development. An outlet structure of some kind is almost always required to maintain a desired water level over an extended time period. Hammer (1992) and SCS (1992) provide examples of outlet structures applicable to the wetlands environment. Most of these structures are similar to those commonly used in small ponds and lakes and serve very similar purposes. Sizing such an outlet structure is relatively straightforward and very similar to sizing an outlet structure for a lake or pond. Since most wetlands will not actively be managed, it is important that the outlet structure operate passively and require little maintenance. These simple outlet structures initially seem to be a perfect solution to establishing a successful and viable wetland. They ensure a relatively constant water surface elevation over a long period of time which allows vegetation to develop and provides a sense of stability. However, this also represents a common fallacy associated with

wetlands development - brilliant engineering and careful planning will provide a wetland environment which is immediately functional and lasts forever. In fact, our desire should be to develop our wetlands to be as similar to natural wetlands as possible. Water levels in natural wetlands vary radically through the water year; a wetland may be completely dry for some period of the year and flooded during other periods. Natural wetlands are very dynamic in nature, evolving through cycles of high productivity and periods of redevelopment driven largely by these hydrologic variations. The author believes one of the most challenging aspects of wetlands development yet to be explored is the design of passive outlet structures which mimic these natural hydrologic variations.

Wetland Vegetation

Vegetation is probably the most visible characteristic of a wetland and an essential ingredient of many wetland functions. Vegetation is a primary component in the processes which remove suspended particles, utilize organic matter, and promotes denitrification. Wetland vegetation also provides cover, food supplies, and nesting and breeding grounds for a variety of wildlife. The richness and diversity of plant species within a wetland indicate its viability and success. The success of promoting the proper vegetation and discouraging undesirable vegetation can determine the success or failure of a wetland project. Thus, establishing conditions conducive to the growth of desirable vegetation must be an integral part of the planning, design, and construction process. Healthy and prosperous growths of desired vegetation result from a combination of desirable physical conditions and nutrient availability. Species diversity is also desirable and may require that a variety of physical environments coexist within a single wetland. Differing water depths, varying soil slopes above and below the normal water level, the permanent retention of water in some areas, or wide ranging current velocities can be utilized to develop these different environments. Conversely, problem species may need to be discouraged in some areas by avoiding physical environments conducive to their propagation. In wetlands which must absorb large quantities of nutrients, harvesting and plant removal can also become important design considerations.

Water depth is probably the most important design criteria for wetland vegetation. Plant survival and propagation depends on proper depth and acceptable inundation frequency. Water depths influence gas exchange between the substrate and the atmosphere and oxygen concentrations in the bottom sediments tend to decrease below deeper waters (Hammer 1992). Thus, the ability of a plant species to transport oxygen to their roots determines the extent of its propagation in certain water depths. Greater water depths can also restrict light penetration and impair the photosynthesis process. However, it can be advantageous to design a wetland with varying water depths to encourage species diversity since many wetland plants flourish within only a narrow range of water depths. In general, wetland plants require water

depths of less than 2 meters and many common wetland plants require water depths less than 1 meter (Steiner and Freeman 1989).

Because of the importance of wetland vegetation, its influence on the design process should not be overlooked. Close coordination between species selection, planting schemes, design concepts, desired wetland functions, and wetland construction are essential to successful wetland restoration, enhancement, or creation.

Water Quality Functions

Water quality improvement is perhaps the most important and least understood wetland function. Hammer and Bastian (1989) indicate that wetlands can effectively remove or utilize large quantities of pollutants including organic matter, suspended solids, metals, and excess nutrients from point sources, such as municipal and industrial wastewater effluents, and nonpoint sources, such as mine, agricultural, and urban runoff. Much of the current interest in the water quality functions of wetlands resulted from the concept of using wetlands in small-scale sewage treatment systems and for stormwater runoff treatment. However, wetlands can also improve water quality within a watershed or drainage basin. By buffering surface and ground waters from various pollutants over long periods, pollutant releases from the basin can be dramatically reduced. Physical, chemical, and biological processes occurring naturally in wetland environments provide water quality improvement through a combination of hydrograph attenuation, vegetative filtering, biological utilization, and chemical conversion. The actual mechanisms through which wetlands improve water quality are discussed in detail by Hemond and Benoit (1988).

Wetlands are increasingly being constructed as part of stormwater control plans. By storing some of the runoff, wetlands can help reduce stormwater flows and improve the quality of the stormwater. Many communities now combine the utility of stormwater retention basins with the ecological functionality of wetlands to temporarily store runoff, provide some hydrograph attenuation, and improve stormwater quality. These wetland systems are often referred to as wet detention basins. The EPA Nationwide Urban Runoff Program (NURP) studies (EPA 1988) demonstrated that these systems exhibit some of the highest pollutant removal efficiencies of any Best Management Practice (BMP). The integration of wetlands within a detention pond can be an efficient use of public funds to provide aesthetic, ecological, and public protection functions in an effective urban runoff treatment project.

Constructed wetlands for wastewater treatment utilize the natural water quality improvement characteristics of wetlands for the direct benefit of society. Few suggest the use of wetlands for primary treatment of wastewater; however, wetlands are currently being used in many areas for tertiary treatment and in some small systems for secondary treatment. Wetlands are not only being used for municipal and household wastes, but also for the treatment of

industrial wastes. Despite numerous successes and extensive publicity, the author would still classify the science of designing wetlands to treat wastewaters to be in the immature stage. Several publications are available which describe currently recommended design methodologies. Hammer (1989) provides a large array of papers related to the use of wetlands for wastewater treatment. Design procedures for treating municipal and industrial wastewaters are described in a number of articles found in Hammer (1989). The use of subsurface flow wetlands to treat wastewaters has also received considerable attention. Reed (1990) provides extensive design procedures and criteria for the application of subsurface flow wetlands to treat various wastewaters.

Riparian wetlands also provide important water quality functions. Large wetland areas in the flood plain can reduce development and provide extensive flood storage and hydrograph attenuation during peak flows. Wetlands also improve water quality within the riparian system, depending upon the amount of the which passes through as it flows downstream. Unfortunately, man's desire for well defined and controlled stream channels has eliminated flow into these wetlands except during flood periods.

Substrate

The wetland substrate, consisting largely of hydric soils, sands, and gravel, provide physical support for plants, a seed bank for vegetative propagation, surface area for various chemical processes such as complexing reactions, and surfaces for attached microbial growth (Hammer 1989). Like hydrology and vegetation, the wetland substrate is an essential component of the wetland ecosystem. Wetland substrates provide habitat for various forms of insect and animal life. Substrate conditions contribute extensively to the water quality functions of a wetland. For example, saturated soils with anaerobic conditions are necessary to remove phosphorous by microbial conversion. Marble (1992) reports that phosphorous removal through chemical precipitation improves when sediments contain high levels of aluminum, calcium, or iron. Wetland substrates can also enhance denitrification of nitrogen laden waters and wastewaters; denitrification is especially effective where conditions at the substrate surface fluctuate rapidly between aerobic and anaerobic stages (Marble 1992). Sculthorpe (1967) found that the wetland substrate also provides a nutrient source for emergent vegetation.

Establishing a wetland substrate capable of providing this level of support at a new wetland site is not easy. Natural wetland substrates develop through years and decades of varying conditions. Transporting substrate from an existing wetland to the wetland being constructed can very effectively reduce the time required to achieve a fully operational wetland. Seed banks contained within the substrate can establish highly desirable vegetative conditions within a few growing seasons. However, obtaining wetland soils from another site can be very difficult unless the wetland project is part of a mitigation plan where existing wetlands are being moved. Even in these cases, care must be taken to carefully remove the soils so as to minimize their disturbance (eg.

changes in moisture conditions) during the transplanting process. In some cases, substrate may have to be stockpiled for several months before being received at the new site. While substrate transplants have been done for some time and are commonplace in some areas, guidance is not readily available to ensure that the removal, storage, and handling process results in a successful transplant. Substrate transplants are quite expensive, but can tremendously increase the chances for a successful wetland project.

In many cases, wetland substrates are not readily available for transplanting and the natural generation process may take many years. Thus, there is a demand for "artificially" created or the development of methods such as seeding which could reduce the time required for the generation process. No indications were found in the literature that researchers have begun to tackle such issues. However, there is clearly a large demand for wetland substrates and many reasons to use well established substrates rather than allow substrates to develop naturally over a long period of time within a new wetland environment.

Summary

Desirable wetland characteristics, their ecological role, and their societal benefits have been described extensively in the literature. Many authors have extolled the ecological functions of natural wetlands including flood control, water quality improvement, fish and wildlife habitat, and groundwater recharge. Others discussed the use of constructed or artificial wetlands for treating municipal and industrial wastewaters. A sufficient literature base was found for most subject areas relating to wetlands: wetlands hydrology, wetlands vegetation, water quality functions, fish and wildlife habitat, legislation, and mitigation. A relatively new literature base has developed which discusses the application of wetlands for wastewater treatment and storm water control.

This plethora of wetlands literature, however, is far from definitive. Most of the existing wetlands research is largely qualitative in nature. Most of the literature describes studies with observations of a limited scope of parameters at a single wetland site or, possibly, a few similar wetland sites. Conclusions based upon these limited observations are relevant to other wetland sites, but natural variations between sites and the complexity of the wetlands ecosystem make broad-based conclusions difficult. Information on some topics is more advanced including some aspects of wetlands hydrology, fish and wildlife habitat, and vegetation. Other topics are less advanced and available design guidance is based largely upon empirical information; these primarily include substrate development, water quality functions, and the application of wetlands to wastewater treatment.

In virtually every area associated with engineering, there remains a significant void of science-based design procedures, parameters, and criteria. For example, hydrology has been described as the single most important parameter in almost every wetland. Extensive studies have attempted to define the

hydrologic characteristics of almost every type of wetland. Additionally, the hydrologic processes which occur within the wetland are identical to those studied in terrestrial and other aquatic systems for decades. However, there still remains a void of general design criteria and analysis tools for ensuring advanced aspects of wetland hydrology such as hydroperiods, flow distributions, and water depth fluctuations which are conducive to the desired wetland functions.

There is also a surprising lack of definitive information regarding water quality functions in wetlands. Wetlands perform a variety of water quality functions through the same general physical, chemical, and biological processes utilized in water and wastewater treatment operations. However, the mechanisms through which some of these processes occur within the wetland are mostly conceptual and have not been conclusively isolated. Resent research has focussed on using artificial or constructed wetlands for treating municipal and industrial wastewaters. Wetlands have been used successfully to treat a variety of wastewaters. Despite the successes and the parallels of the treatment processes with traditional wastewater treatment operations, there is still considerable disagreement over some of the basic mechanisms of treatment. Additionally, the available design criteria are mostly empirical and difficult to apply under conditions different from those under which they were developed.

Acknowledgements

This study was funded by the Environmental Laboratory of the USAE Waterways Experiment Station as part of the Wetlands Research Program (WRP). The Center for Infrastructure Research at the University of Nebraska-Lincoln also provided assistance for the project.

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Development of Conceptual Design Criteria for Wetlands Restoration, Lawson M. Smith, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS

Abstract

Wetland design criteria are instructions or guidelines for developing biological, hydrological, geological, and engineering design specifications for restoration or creation of a wetland of a specific type to achieve specific wetland functions. Design criteria should not be confused with design specifications which are detailed designs of features such as hydraulic structures or earthwork, usually detailed in design drawings. Design criteria are based on the knowledge of the biological, hydrological, chemical, and geological processes and conditions of wetlands and their interaction to produce certain recognized functions. The goal of design criteria is to provide instructions that will result in a wetland restoration or creation project that achieves the target functions while attaining a level of equilibrium with the larger landscape system.

The purpose of the Design Criteria Work Unit in the Corps of Engineers Wetlands Research Program is to develop hydrological, biological, geotechnical, and engineering design criteria for four basic kinds of wetlands to provide the eleven wetland functions defined by the Wetland Evaluation Technique. There are five research areas in the work unit: hydrology, wetland plants, wetland fauna, geotechnical, and engineering structures. The four types of wetlands are defined by the "Hydrogeomorphic Classification of Wetlands" as fringe (coastal), riparian, depressional, and slope. For each combination of wetland type and function, the five types of wetland design criteria are being developed. The principle product of the research effort will be a document providing design criteria for the four basic types of wetlands and eleven functions.

(Paper not provided)

Development of U.S. Army Corps of Engineers' Guidance for Wetlands Engineering, Michael R. Palermo, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi

Introduction

Wetlands restoration projects require a unique combination of engineering and scientific disciplines. Perhaps because the nature of this technical area is so strongly interdisciplinary, technical guidance has not yet been developed to a sufficient level of detail for routine application. General guidance on various aspects of wetlands design and construction is available (Environmental Laboratory 1978, Federal Highway Administration 1990, Hammer 1992, USDA Soil Conservation Service 1992). However, there is a need to develop more comprehensive and detailed guidance.

A successful wetlands restoration project must be based on a thorough understanding of wetland functions and processes along with their related engineering design considerations. The U.S. Army Corps of Engineers (USACE), as a part of its Wetlands Research Program (WRP), is developing technical guidance on the engineering aspects of wetlands restoration. This emerging field can be referred to as "Wetlands Engineering." This paper describes ongoing efforts by the USACE to develop technical guidance for wetlands engineering.

Design Considerations

Wetlands needs, site characteristics, and design criteria; fill or excavation equipment and techniques for wetlands soils; wetlands hydrology and flow control; erosion protection; and techniques and materials for establishing wetlands vegetation must be considered in planning, design, and construction of wetland enhancement and restoration projects. The technical approach for engineering these projects should based on the concept that design activities associated with establishing and protecting wetland substrate and providing the proper hydrology and hydraulics should precede those associated with establishing wetland vegetation. This design sequence was recently developed as a part of the WRP (Palermo 1992) and is illustrated in Figure 1. This sequence of planning, design, and construction related activities provides the framework for development of Wetlands Engineering guidance by the USACE.

Wetlands Engineering Guidance

A series of technical notes, reports, handbooks, and computer software related to Wetlands Engineering are available from the WRP to support many of the requirements of wetlands restoration projects. These WRP documents cover topics such as the recommended design sequence, vegetation selection

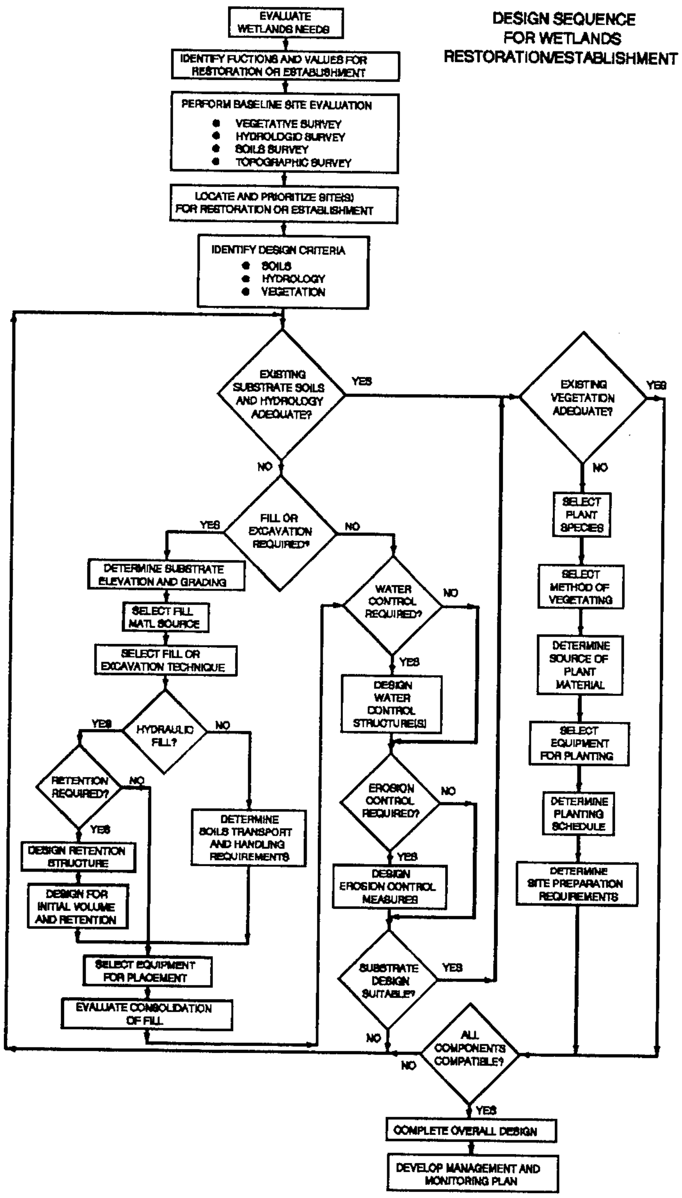

Figure 1. Design Sequence for Wetlands Restoration Projects

and establishment techniques, soils handling equipment and techniques, wetlands hydrology, and wetlands hydrodynamics. Many of these documents provide details for the steps illustrated by the design sequence in Figure 1. Pertinent information from these WRP documents will be combined to develop USACE handbooks on Design Criteria and Wetlands Engineering which will be the primary technical guidance documents oriented toward field use. These handbooks will incorporate field experience and the results of research and will build upon and supplement earlier guidance documents prepared by the USACE, Soil Conservation Service, Federal Highway Administration and others.

The Design Criteria Handbook will contain separate criteria for a variety of wetlands functions and geomorphologic wetland types. These criteria will define parameters such as depth and duration of flooding, soil characteristics, and vegetation requirements to support the desired functions. The Wetlands Engineering Handbook will provide the design and construction guidance. In addition to these manuals, a computer software package entitled WETER is being developed to assist the designer. WETER is a decision support system which will include modules on planning and site selection, design implementation, monitoring and management. A framework for this software package is complete and the initial version should be available along with the Design Criteria and Wetland Engineering Handbooks. The goal is make these handbooks loose-leaf, easily updated, and with detailed information on planning, design, and construction of wetlands restoration projects. A draft outline showing the major topics to be covered by the Wetlands Engineering Handbook is shown in Figure 2.

This workshop on Wetlands Engineering (convened in St. Louis, MO, in August 1993) provides a forum for exchange of information on engineering techniques for wetlands restoration and enhancement projects and will be a primary source of technical information for development of Wetlands Engineering guidance. Over 225 representatives of Federal, State, and Local governments, private consultants, and others are participating. Over 50 technical papers are to be presented, and these papers will hopefully provide a comprehensive base of information for the development of the Handbooks. Working sessions will provide all the participants a direct forum for input on the content of the Design Criteria and Wetlands Engineering Handbooks to be developed under the WRP.

Conclusion

The design activities for wetlands restoration and establishment include consideration of wetlands needs, site characteristics, and design criteria; fill or excavation equipment and techniques for wetlands soils; water and erosion control structures for wetlands hydrology; and techniques and materials for establishing wetlands vegetation. The recommended sequence for design is based on the concept that activities associated with establishing wetland substrate soils and hydrology should precede those associated with establishing

INTRODUCTION
- Background
- Purpose and Scope

DEFINING FUNCTIONS, SITE CHARACTERISTICS, AND DESIGN CRITERIA
- Initial evaluation of wetlands needs
- Selection of desired wetland type and functions
- Baseline site surveys
  - Topographic
  - Hydrologic
  - Soils
  - Vegetative
- Selection of sites for restoration
- Design criteria

ENGINEERING FOR WETLANDS SUBSTRATE
- Suitability of existing substrate soils
- Fill or excavation requirements
- Elevation and grading requirements
- Borrow material sources for fill requirements
- Placement sites for excavated material
- Fill or excavation techniques and equipment
- Hydraulic fill requirements
  - Retention requirements for hydraulic fill
  - Retention dike or structure
  - Selection of hydraulic fill equipment
- Conventional soils handling
  - Soils handling requirements
  - Select equipment for soils handling techniques
- Consolidation of fill

ENGINEERING FOR WETLANDS HYDROLOGY
- Modeling
  - Drainage analysis GeoSHED
  - Hydrodynamics FastTABS
  - Groundwater
- Requirements for water control
- Design of water control structure(s)
- Requirements for erosion control
- Design of erosion control measures

ENGINEERING FOR WETLANDS VEGETATION
- Vegetation requirements
- Species selection
- Methods of vegetating
- Source(s) of plant materials
- Equipment for planting
- Planting schedules

AUTOMATED SYSTEMS AND SOFTWARE
- WETER

MONITORING AND MANAGEMENT
- Construction Monitoring
- Physical/Engineering
- Chemical/Biological
- Success Criteria
- Management and monitoring plans
- Remedial actions

Figure 2. Draft Outline For Wetlands Engineering Handbook

wetland vegetation. By following an efficient sequence of activities for design, duplicative and unnecessary evaluations can be avoided and a fully integrated design will result. Future research planned under the Wetlands Research Program will provide more detailed guidance on Wetlands Engineering, and Design Criteria and Wetlands Engineering Handbooks are planned to provide comprehensive technical guidance for field use.

Acknowledgement

The information in this paper resulted from research efforts under the U.S. Army Corps of Engineers Wetlands Research Program conducted by the U.S. Army Engineer Waterways Experiment Station. The Chief of Engineers granted permission to publish this information.

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Development of a Handbook for Wetland Restoration and Creation, Robert E. Holman and Wesley Childres, Water Resources Research Institute, North Carolina State University, Raleigh, North Carolina

Introduction

Background

Of the estimated 274 million acres of wetlands in the United States, North Carolina ranks sixth in the number of existing wetland acres (Dahl, 1990). The original amount of wetlands in North Carolina is thought to be over 10 million acres and current figures find 49 percent of the original acreage to be impacted. Impact in this case is whether the wetland is partially supporting, or nonsupporting its original uses. Wet pine flatwoods and ponds, the only two wetland types that have increased over time, have increased by approximately 1.7 million acres (NCEHNR, 1992). Of all the wetlands located in North Carolina over 95 percent are found in the 41 counties that make up the coastal plains. This is based on U.S. Soil Conservation Service estimates of hydric soils in each county. Steps have been taken by state and federal agencies to curb the number of acres lost to development activities. Wetland restoration and creation are becoming a more common component of the regulatory program, and the U.S. Fish and Wildlife Service is restoring wetlands on its refuges. However, there is only one known national guidance document on wetland creation and restoration techniques. This is a chapter developed by the U.S. Soil Conservation Service in 1992 as part of their Field Handbook.

Purpose

The Water Resources Research Institute has undertaken a project to develop a techniques handbook for the restoration and creation of wetlands. Funds for this project have been provided by the North Carolina Division of Coastal Management. The project is being carried out in three phases. Phase One consists of identifying techniques used for wetland creation and restoration through a literature review and consultation with wetland experts currently involved in restoration and creation projects. Phase Two is to develop and distribute a questionnaire concerning specific restoration and creation techniques being utilized by wetland experts. Phase Three is to compile a handbook incorporating information from the literature, on-going projects, and expert opinion from the questionnaire for approximately six wetland types found in the Southeastern United States. The six wetland types are brackish marsh, freshwater marsh, estuarine scrub-shrub, pocosin, bottomland hardwood, and swamp forest.

Handbook Components

Phase one

A literature review revealed over 350 references on restoration and creation of wetlands. One excellent source of information was a review of the literature conducted by the U.S. Fish and Wildlife Service in 1990. The reference is titled "Wetland Creation and Restoration: Description and Summary of the Literature" and referred to as Biological Report 90(3). This report has summarized over 1100 articles on wetland creation and restoration from 1940-88 and indexed them by plant genus, location, subject, and wetland type. Some interesting findings from the Fish and Wildlife review include: the number of articles published started to increase rapidly in the mid-1970s (Figure 1); the state with the highest number of references was Florida; planting and landform (modification of topography) was the most frequently employed procedure, activity, or method for restoration and creation (Figure 2); the most frequently measured, monitored, or evaluated response was through the vegetation variable; and the most cited types of wetland were freshwater types. When the current literature review was crossed referenced with the Fish and Wildlife document there were 200 additional articles. More than half of these articles were from 1988-92. Many of the articles are focused on the status and trend of wetlands, classification and value of wetlands, and specific research on soil, nutrients, hydrology and vegetation involved with restoration and creation activities.

The second aspect of Phase One is to determine how many restoration and creation projects have been or are currently being undertaken in North Carolina. These projects fall under one of two components that include the regulatory and non-regulatory. The regulatory component involves both mitigation and enforcement actions tied to the permitting process (Section 404 of the Clean Water Act) that is regulated by the U.S. Army Corps of Engineers (USACOE). There are approximately 45 mitigation projects covering 460 acres (available data from 1991-93). The North Carolina Department of Transportation (NCDOT) has 16 projects involving approximately 200 acres, and the remaining 29 projects and approximately 260 acres are non-NCDOT projects. There are approximately 125 cases per year that some form of enforcement action is required by the USACOE. In 90 percent of the cases, this usually means restoring a wetland by removing the material that has been placed on it and allowing the site to revegetate naturally. Currently, the acreage figures for the wetland enforcement actions are not available (Wayne Wright, U.S. Army Corps of Engineers, Wilmington, NC and Ron Ferrell, N.C. Division of Environmental Management, Raleigh, NC, July, 1993). The non-regulatory projects appear to be mainly associated with the U.S. Fish and Wildlife Service efforts to restore wetlands to their original state on the National Wildlife Refuges, conservation easements, and private land. There are approximately 1200 acres that are actively being converted back to wetland habitat (Mike Wicker, U.S. Fish and Wildlife Service, Raleigh, NC, July, 1993). Contacts are currently being made with the individuals that are

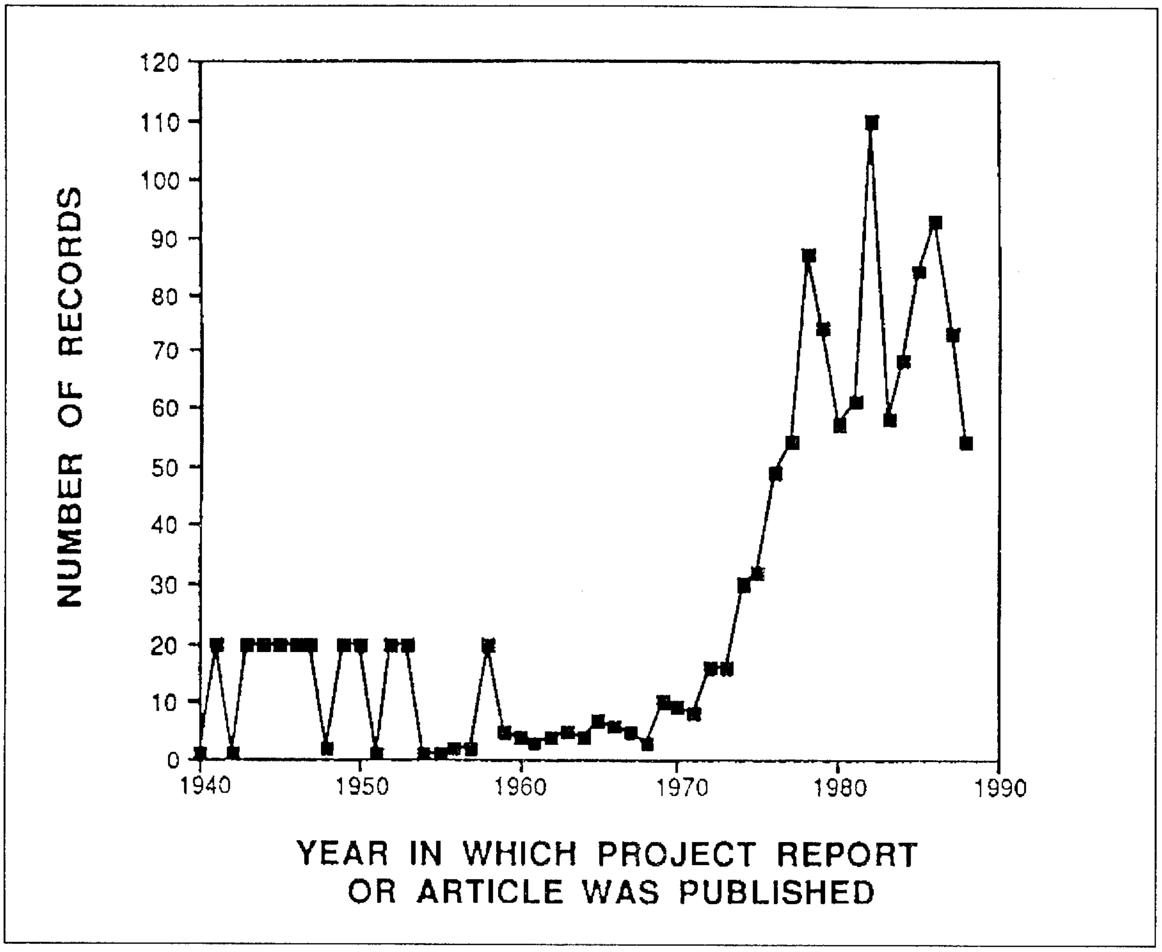

Figure 1. Source: Schneller - McDonald, et al., 1990

conducting the actual wetland restoration and creation work to gather the techniques that are being employed for the six different wetland types.

Phase two

The development and distribution of a questionnaire concerning specific restoration and creation techniques is now being completed. This questionnaire is being reviewed by a panel of wetland and survey development experts. The questionnaire is divided into four sections including background, vegetation, hydrology, and personnel. There are 30 questions that are multiple choice and listing type of questions. Plans are to send the questionnaire to approximately 300 wetland restoration and creation practitioners for their opinions. The survey results will be incorporated in the procedural handbook.

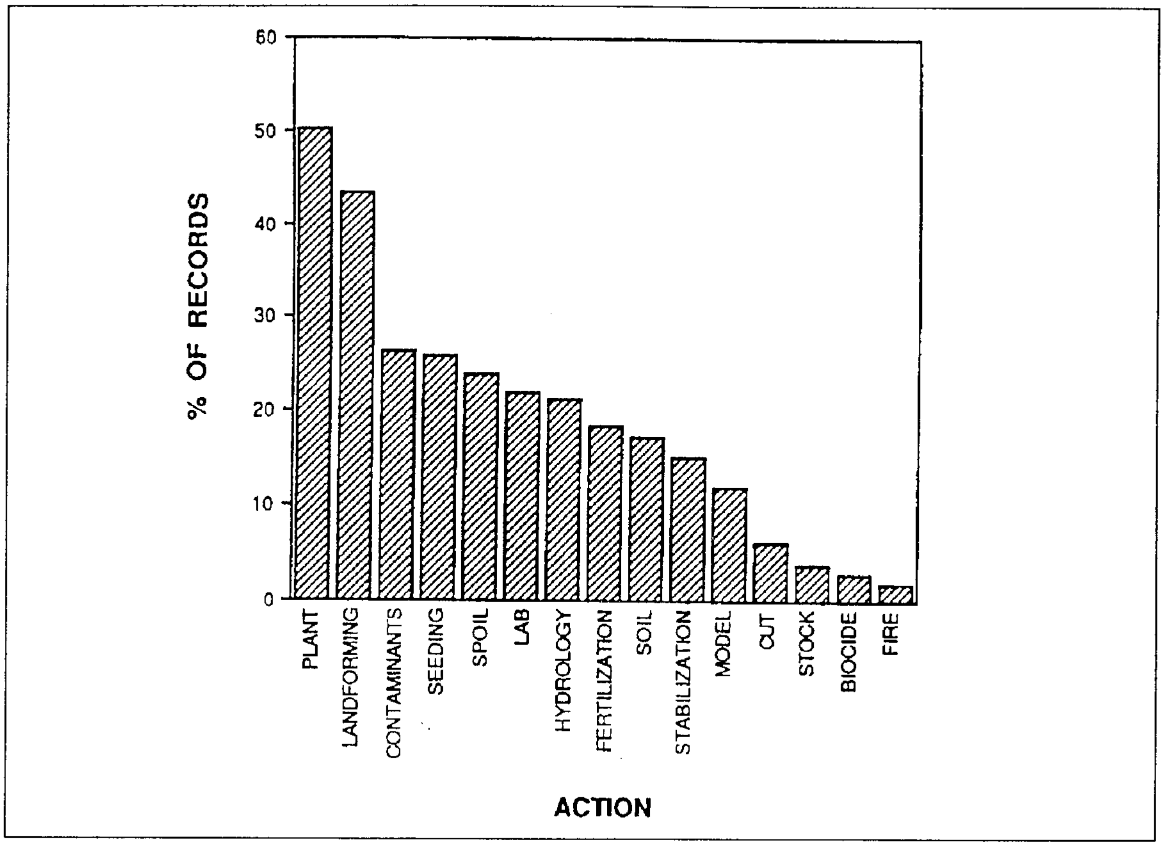

Figure 2. Source: Schneller _ McDonald, et al., 1990

Phase three

The techniques handbook will incorporate information from the literature, on-going projects, and expert opinion from the questionnaire for the approximately six wetland types found in the Southeastern United States. Sections of the handbook will contain: 1) an overview of considerations and techniques for wetland restoration and creation; 2) questionnaire summary with results; and 3) a "how to" guide for the restoration and creation of six wetland types. The handbook should be completed by the end of 1993.

Conclusion

Studies have shown that a large portion of mitigation projects are not successful. A study of mitigation projects in south Florida (Erwin, 1991) showed that only 10 percent of the projects were actually successful in meeting all of the stated goals (Figure 3). This poor success rate is probably not just reflective of Florida but in many other states. There is only one national wetland restoration and creation techniques document that is currently available from

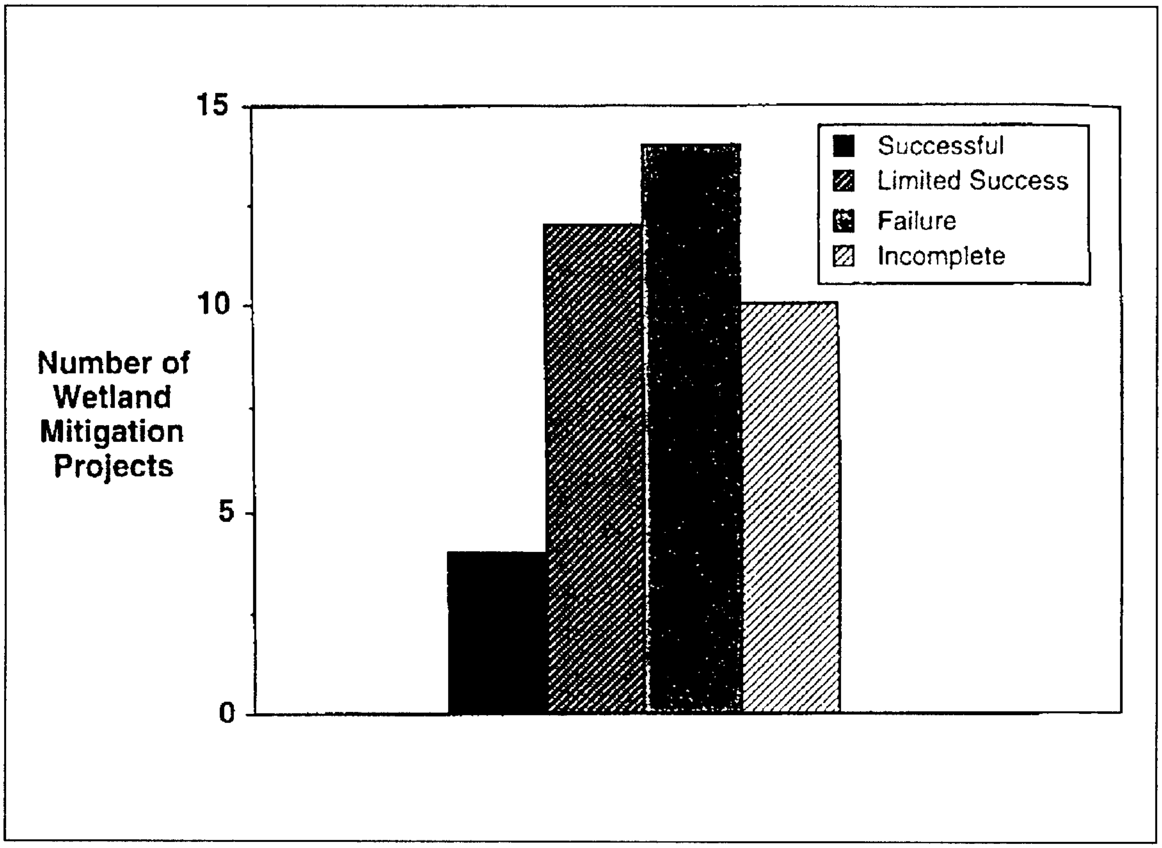

Figure 3. Source: Erwin, 1991

the U.S. Soil Conservation Service. Therefore, a critical need exists to develop usable guidance documents on successful techniques in restoration and creation for specific wetland types. The development of this handbook will provide the North Carolina Division of Coastal Management with proper guidance to restore and create wetlands in the Southeastern United States.

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Engineering of the La Branche Wetlands Restoration Project, St. Charles Parish, Louisiana, Richard W. Broussard Jr., and Edwin M. Dickson Jr., U.S. Army Corps of Engineers, New Orleans District New Orleans, LA

Abstract

The LaBranche Wetlands Restoration Project is proposed for an area along Lake Pontchartrain in southeast Louisiana near New Orleans. Sediments dredged from the lake near the mouth of a Mississippi River flood control spillway are to be pumped in a retaining area to a height conducive to wetlands development. This paper presents the design approach utilized in engineering this Coastal Wetlands Planning, Protection, and Restoration Act (CWPPRA) project. Design features include controlled placement of dredged material, retaining structures, closures, weirs, and effluent control management. Data collection, and field investigations utilized in the site selection and assessment process are presented, along with the establishment of engineering properties and criteria for the wetlands substrate design.

Overview

The project - "Restoration of the La Branche Wetlands" is authorized under the Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA), otherwise known as the Breaux/Johnston Bill. The CWPPRA was authorized under Public Law 101-646, adopted 29 Nov 90. The bill provides the State of Louisiana with approximately $35 million per year, over a 5-year period, to cover costs for the development, screening, engineering and design, construction and contract administration, and monitoring of alternatives which may be of significant use in the prevention of loss and restoration of wetlands within the Louisiana coastal zone. The "La Branche" project was developed and selected as part of the "CWPPRA - First Priority List".

Location

The project is located approximately 22 miles west of New Orleans in the Bayou La Branche Wetlands in St. Charles Parish, Louisiana. The area is immediately adjacent to the lower (east) guide levee of the Bonnet Carre' Spillway. It is also bounded on the north side by Lake Pontchartrain and the U.S. Interstate 10 on the south, from which the site is highly visible.

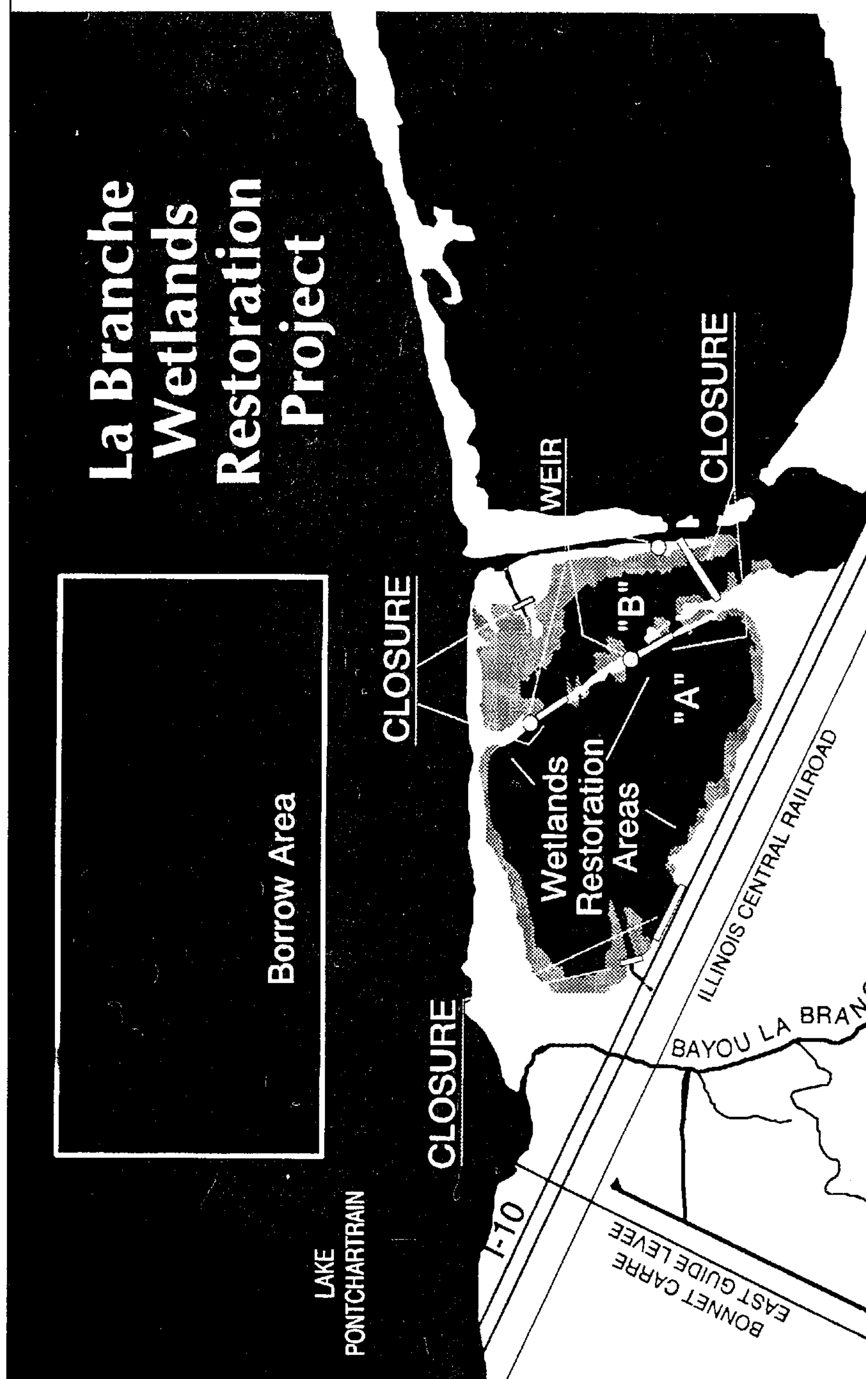
La Branche
Wetlands
Restoration
Project
Borrow Area
CLOSURE
CLOSURE
WEIR
CLOSURE
"B"
"A"
Wetlands
Restoration
Areas
ILLINOIS CENTRAL RAILROAD
BAYOU LA BRANCHE
I-10
LAKE
PONTCHARTRAIN
BONNET CARRE
EAST GUIDE LEVEE

Figure 1

Justification

The La Branche Wetlands consists of fresh and intermediate marshes. Approximately 360 acres of open water exists at the site as a result of long term subsidence. The close proximity of bundant sediments within Lake Pontchartrain provides us with an ideal opportunity to restore these deteriorated areas through dredging for the express purpose of creating vegetated wetlands.

Objective

The purpose of the project is to transform approximately 360 acres of open water to intermediate vegetative wetlands.

Design and Construction Features

Field surveys of the borrow area and wetland restoration sites were performed in May 92. Analysis of these surveys revealed the following:

a. The average elevation within the wetland restoration areas is approximately (-)0.5 feet National Geodetic Vertical Datum (NGVD);

b. Elevations within the borrow area range from (-)3.0 NGVD to (-)10.0 feet NGVD;

c. Elevations about the perimeter of the wetland areas range from a minimum of 0.0 NGVD to a maximum of approximately +4.5 feet NGVD along the south side of Lake Pontchartrain (northern limit of restoration sites); and

d. Approximately 2.5 million cubic yards of borrow will be required to obtain a desired net (final) elevation of approximately +1.5 feet NGVD after immediate consolidation (first 6-8 months).

The work will be accomplished by hydraulic cutterhead dredge with the material excavated from the borrow site in Lake Ponchartrain, transported via pipeline to and placed within wetland restoration areas "A" and "B". Prior to placement of the material within the restoration areas, retention structures will be constructed by the Contractor in order to retain the material within the areas. These may include perimeter structures, along with closures and weirs at specified locations. The exact type of retention structures to be used (i.e., earthen dikes/closures, geotextile tubes, hay bales, etc.) will be an option for the Contractor. The type of retention plan and structures to be used will be dependant upon the size plant selected by the Contractor for this work, as well as special operations of said plant such as throttling down, use of baffles and "Y" valves, and regulation of weirs to maximize retention of sediments and sufficiently drain the areas.

The discharge shall be closely monitored and positioned so as to create a series of mounds within the wetland restoration areas. The discharge elevation will be limited to a maximum of +4.0 feet NGVD. No direct discharge will be allowed upon existing wetlands nor within 1,000-feet of the Interstate 10 bridge. The initial point discharge location will be at the western-most end of restoration area "A" (primary restoration area) and, upon reaching an elevation of approximately +4.0-feet at the discharge location, the discharge point will be moved in approximately 1,000-foot increments, in a clockwise manner towards the east. Upon filling area "A" to its capacity, the discharge will be moved to area "B" (secondary restoration area).

The initial point discharge location within area "B" will be immediately adjacent to the shoreline of Lake Ponchartrain. Once area "B" is filled to its capacity, we will have created approximately 360 acres of intermediate vegetative wetlands ranging from +0.5 to +1.5 feet NGVD.

Monitoring Program

Surveys (before and after cross sections) of the areas will be required of the Contractor. They will be referenced to permanent post (4 x 4 or 3" PVC pipes) to be established prior to disposal. This data will be used by Corps and state officials for periodic monitoring of the development of the wetlands areas.

Project Schedule

Final engineering and design work has recently been completed. We anticipate advertising the work around 10 Aug 93, for a 30-day solicitation period. Award is scheduled for 16 Sep 93, with approximately 6 months required to complete the project.

Geotechnical Evaluation

Soil borings and other engineering data available

Twelve general type soil borings were taken for the project. Eight borings were taken in Lake Pontchartrain North of the project site, in a large area originally identified as the potential source of borrow. Of these 8 borings taken, 3 borings are located in the area ultimately selected for borrow, and 1 boring was located close to the perimeter of that area. 4 Borings were taken in the project site to receive hydraulic fill. All of the borings were taken with a wire line sampling rig mounted on the back of swamp buggy. This setup performed quite nicely while operating in 10 feet of water for the Lake borings, and 1 foot of water for the restoration area borings.

In addition to this data we were also able to obtain soil borings and test data from an erosion control dike project just East of the project site. Data from this project designed by a local consulting engineer for the State, included some shear strength and consolidation test data.

Another source of boring and shear test data was available from construction records of the elevated Interstate 10 Hwy along the Southern boundary of the project.

Additionally our data from the Bonnet Carre Spillway containment levee west of the project was also available.

Foundation

The foundation consists of a layer of highly organic peat with high water contents extending to approximate El. -13 feet NGVD. The peat is underlain by a layer of lean to fat very soft clay and silty clay extending to the limits of the borings at approximate El. -25 feet NGVD.

Conceptual depiction of the hydraulic fill section

We estimated the geometry of the hydraulic fill placement as shown in figure 2. We anticipate the hydraulic fill will penetrate and displace the lighter peat layer to produce a cone of material between 400 and 1200 ft. in radius with an estimated crown elevation between +4.0 and +6.0. The presence of a firm foundation would correspond to the smaller radius, and likewise require more movement of the dredge discharge pipes. Such displacements could produce a mud wave of peat to elevations as high as +3.0 or +5.0 as shown in figure 2. The actual geometry could vary considerably within the area to receive fill.

Estimated settlement

We estimated settlement at the high points of the hydraulic fill discharge, and mud wave. These points represent the areas of greatest anticipated settlement.Other areas within the containment area should exhibit less settlement. Stress-strain characteristics obtained from borings at the shore line of Lake Pontchartrain just East of the project were used to approximate those properties for our estimate.

Figure 3 represents an estimate of time vs elevation for the center of a typical hydraulic fill cone. You will note this graph indicates in 20 years the height of fill is negative. We do **not** expect the ground surface to be lower at this point than the original ground surface. The displaced peat is expected to gradually migrate back over the edges of the hydraulic fill when it settles

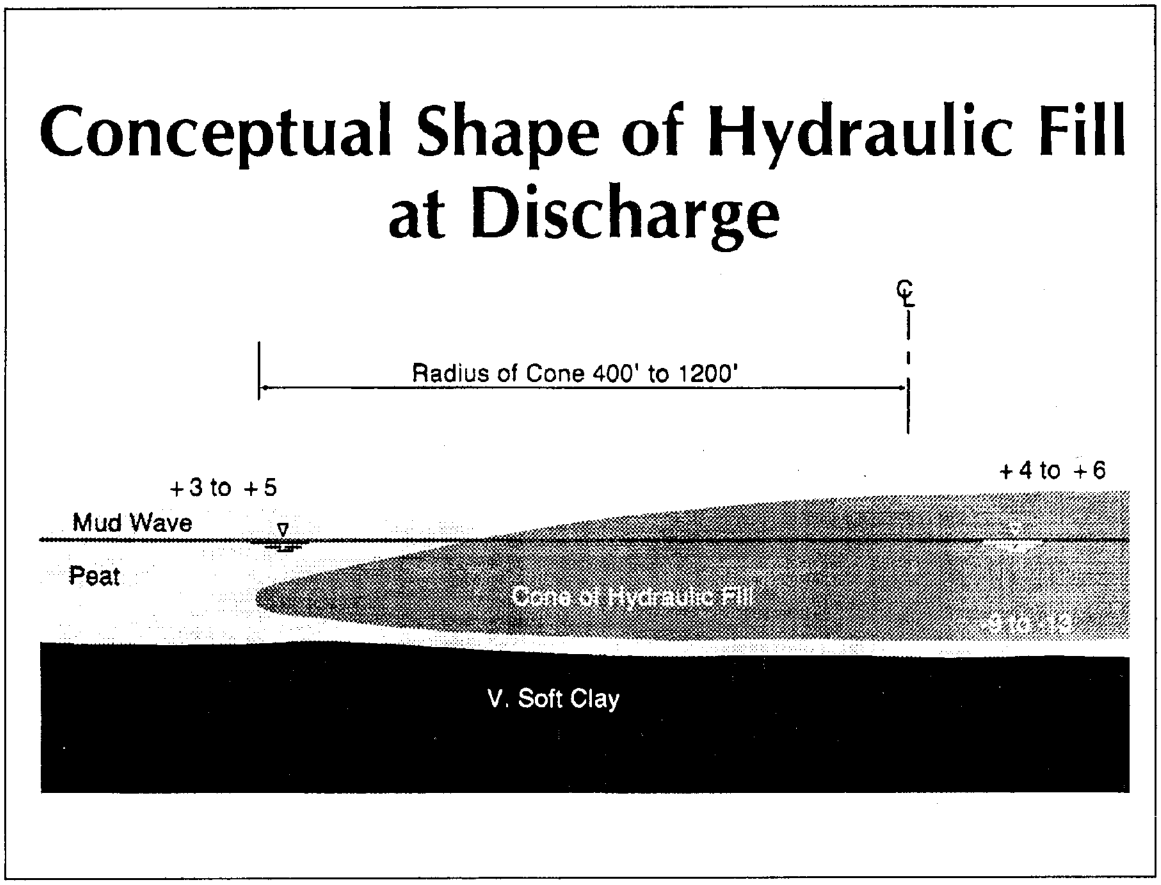

Figure 2

below the average height of displaced fill. The volumes indicated in the legends are estimates of hydraulic fill contained within a single cone of material. The deposition of additional cones will encroach upon each other ultimately resulting in a net gain in elevation of the site. The smaller volume corresponds to fills placed on favorable foundations to crown elevation +6. The larger volume corresponds to fills placed on a less favorable foundations to crown elevation +4.

The time dependent properties of the foundation materials used in predicting consolidation were also obtained from the borings just East of the LaBranche project.

Through estimates of displaced volumes of materials vs. lost volumes due to shrinkage and consolidation, a net gain after 20 years of 1.0 to 1.5 ft is anticipated in the most confined area to receive fill.

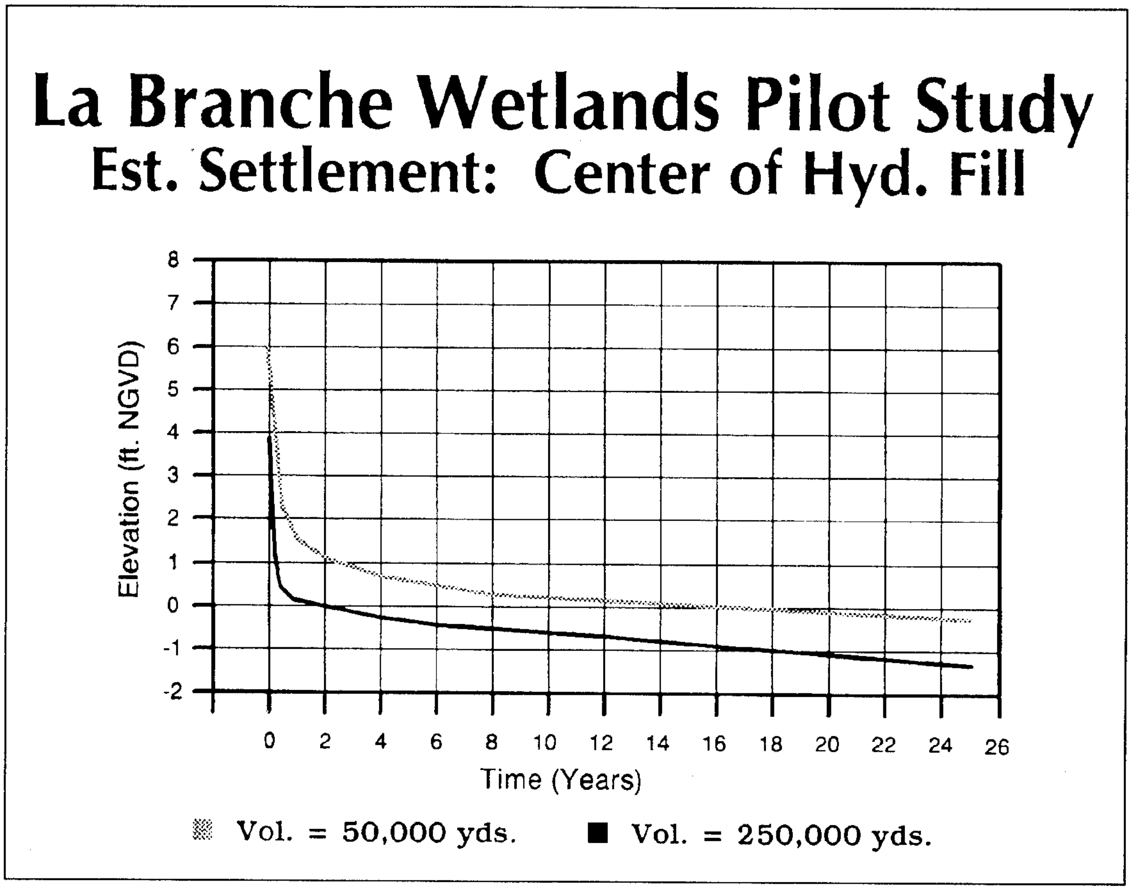

Figure 3

Retaining dikes

Our design philosophy addressing the specifications of retaining dikes was driven primarily toward encouraging the contractor to use new and innovative techniques to retain and control the dredged material. We therefore recommended the inclusion of geotube dike construction as an option, in addition to a traditional dike constructed from native materials. Typical designs provided as a basis for cost estimating were developed from empirical correlations with the shear strength data from the borings East of the project.

Lessons learned in the geotechnical evaluation

An evaluation of the engineering properties of the foundation soils beneath the substrate, (root zone) of the wetlands area is necessary to meet the primary design objective of most projects constructed in South Louisiana.

Monitoring of elevations, and strategically located soil borings 25 to 40 ft. deep is required on more projects in remote areas of South Louisiana to provide an empirical data base to evaluate the dynamic response of the construction loadings placed on these wetlands foundations.

Intertidal Habitat Restoration in an Urban Environment: The Federal Center South Coastal America project, Patrick T. Cagney,[1] and Curtis D. Tanner[2]

In February of 1993, the first of three intertidal habitat restoration projects planned for the Duwamish River Estuary (Seattle, Washington) was completed. This project was a cooperative effort by five federal agencies, and was funded through the Coastal American program. Designed to demonstrate and test restoration techniques applicable to an urban environment, project elements include substrate enhancement, intertidal bench construction, pier demolition and piling removal, fill removal and regrading, bankline planting, and floating log booms. Ecological goals of the project focused on restoration of habitat types historically abundant in the lower Duwamish. Unvegetated mud/sand flats, emergent marsh, and forested shorelines, important to a variety of fish and wildlife species, have been nearly eliminated from this system. Long-term monitoring of this and the two other Coastal America project sites will insure that this program contributes to an increased understanding of habitat restoration techniques and improved future project design.

Puget Sound's fjord like topography offers few relatively flat areas to exploit. As the region developed, coastal wetlands and mudflats became the focus for a variety of industrial, commercial, and residential purpose. In the Duwamish River estuary, surrounded by the city of Seattle, approximately 98% of historic intertidal marsh and mudflats have been lost, and tidal forested wetlands have been completely eliminated form the system. While currently used for a variety of economically important industrial and marine cargo transportation uses, the estuary also provides a critical link between a large riverine system an the open waters of Puget Sound. The destruction of intertidal habitats, critical to juvenile salmon and other fish species, shorebirds, and waterbirds, and well as many species of shellfish, mammals, and amphibians, represents a threat to the ecological integrity of both the Duwamish estuary, and to greater Puget Sound.

Recognizing the importance of wetland habitat loss, the Puget Sound Management Plan (a Comprehensive Conservation Management Plan under the National Estuary Program) directs several Federal and State agencies to implement a program of wetland restoration to complement existing regulatory efforts, which are designed to minimized, not prevent habitat losses from development projects. Programs such as §404 of the Clean Water Act can, at best, be relied upon only to "hold the line", and can not be realistically be expected to repair damaged systems like the Duwamish. This Coastal America

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[1] U.S. Army Corps of Engineers, Seattle District, Environmental Resources Section, Seattle, Washington.
[2] U.S. Fish and Wildlife Service, Ecological Services, Puget Sound Program, Olympia, Washington.

project was developed in response tot he call for a more proactive approach to wetland resource protection. Additionally, the project is intended to serve as a pilot for urban mitigation projects as well as restoration activities to be completed in the Duwamish under Superfund and NRDA provisions of CERCLA.

Coastal America project sites and designs have been selected to achieve a variety of ecological and technical objectives which focus on riparian, marsh, mudflat, and subtidal channel habitat restoration. New approaches will be demonstrated, and old techniques are being modified for use in this urban environment. In addition to activities completed at Federal Center South, (which is the subject of this paper), two other sites will be completed during 1993/94. For one project site, derelict vessels and fill material will be removed from intertidal areas. Regarding of the existing slope at the landward edge will allow for tidal marsh restoration, and a riparian buffer will be established. At the other site, an existing drainage ditch will be rerouted and expanded to create a tidal slough. The mouth of the slough will be planted with saltmarsh vegetation. Riparian buffer and public access features at the site will also be improved.

The Federal Center South project site consists of approximately 1,000 linear feet of riprap stabilized shoreline (2 to 1 slope) along the Duwamish in a moderate energy environment. Boat wakes form barge traffic, river currents, and a 15 ft. tidal range contribute to slope instability and erosion at the site. The property is owned by the U.S. Government General Service Administration (GSA), and has not been actively used for a number of years. The northern end of the project site contained a small area of bulrush (*Scirpus acutis*) and a large (approximately three story) shed built out over the intertidal area on pilings. The shed originally contained an anti-submarine device used during World War II, and has since been abandoned. The location of the shed limited the extent of intertidal vegetation due to shading effects.

Much of the pre-construction phase of the project was taken up in defining agency and local sponsor roles and preparing interagency agreements. These agreements were necessary to transfer multi-agency funds to the Corps for project oversight and implementation, and to gain access to the GSA property by the Corps. Regulatory processes were simplified due to the federal ownership of the property, eliminating the need for local grading permits. Required permits included Washington State Water Quality Certification (§401 of the CWA) and a State Hydraulics Permit (administered by the Washington Department of Fisheries). The project also required Section 10/404 permitting from the Corps. Completion of the permit process took approximately six months.

A critical step in the restoration process involved site evaluation. At Federlacementr South, a physical survey was completed to determine existing elevations and slopes. Due to the site's location in an industrial area, soils, and surface sediments were evaluated for chemistry and grain size. Based on this information and given site budget constraints, the following ecological goals were developed:

a. Increase area and associated functions (primarily prey resource support) of fine grained unconsolidated (i.e. mud/sand flat) habitat;

b. Increase acreage and associated functions of tidal marsh habitat;

c. Increase riparian habitat in terms of both physical structure (i.e. buffer) and biological productivity; and

d. Provide bank stabilization and erosion control to prevent loss of restored and enhanced habitats.

These goals were then used in developing the design for this site (Figure 1).

Increases in the area of mud/sand flat habitat were achieved through construction of an intertidal bench approximately 10 ft wide and 125 ft long. This bench was constructed by reconfiguring the existing riprap slope and the placement of bench or step at an elevation of +2 ft Mean Lower Low Water (MLLW). Tidal range at the site is approximately -3 to +12 MLLW. Sediment supply was augmented by placing 200 cubic yards of clean fine grained material at the upstream end of the project site.

Two separate approaches were utilized to increase the size of the tidal marsh area. First, shading impacts were eliminated by removal of the shed structure an associated pilings. Second, fill material was removed and some 6,700 ft^2 regraded to the elevation of the existing marsh (+9 MLLW). Because of the adjacent seed and rhizome source, planting is not considered necessary and these areas will be allowed to revegetate naturally.

The establishment of a riparian buffer was another important objective of the project. To facilitate the establishment of bankline vegetation it was necessary to clear a trench between the top of the existing riprap slope and an adjacent fence. The trench was back filled with top soil and mulch. Native trees (shore pine, alder, willow, and Sitka spruce) and shrubs (red currant, salal, and indian plum) were planted. A drip irrigation system was installed to ensure survival of bare root stock.

Finally, in an effort to control bank erosion and to protect marsh vegetation from boat wakes, both tree trunk/root ball material and small rock groins were installed perpendicular to the shoreline. These structures (3 each, 6 total) were built between +2 and +5 MLLW to capture and retain sediments migrating downstream. It is anticipated that the root balls and rock groins will also provide refuge for small fish. Additionally, a floating log boom was anchored to existing dolphins (piling groups) along the length of the project area to further attenuate wave energy and prevent debris accumulation.

Project construction was completed in 90 working days. Equipment utilized included hydraulic excavator, bull dozer, dump truck with pup, barge with crane and clam shell bucket, and pile driver. Materials used were rock (800 lbs. minus), silty sand, top soil, mulch, and bare root plant stock. The

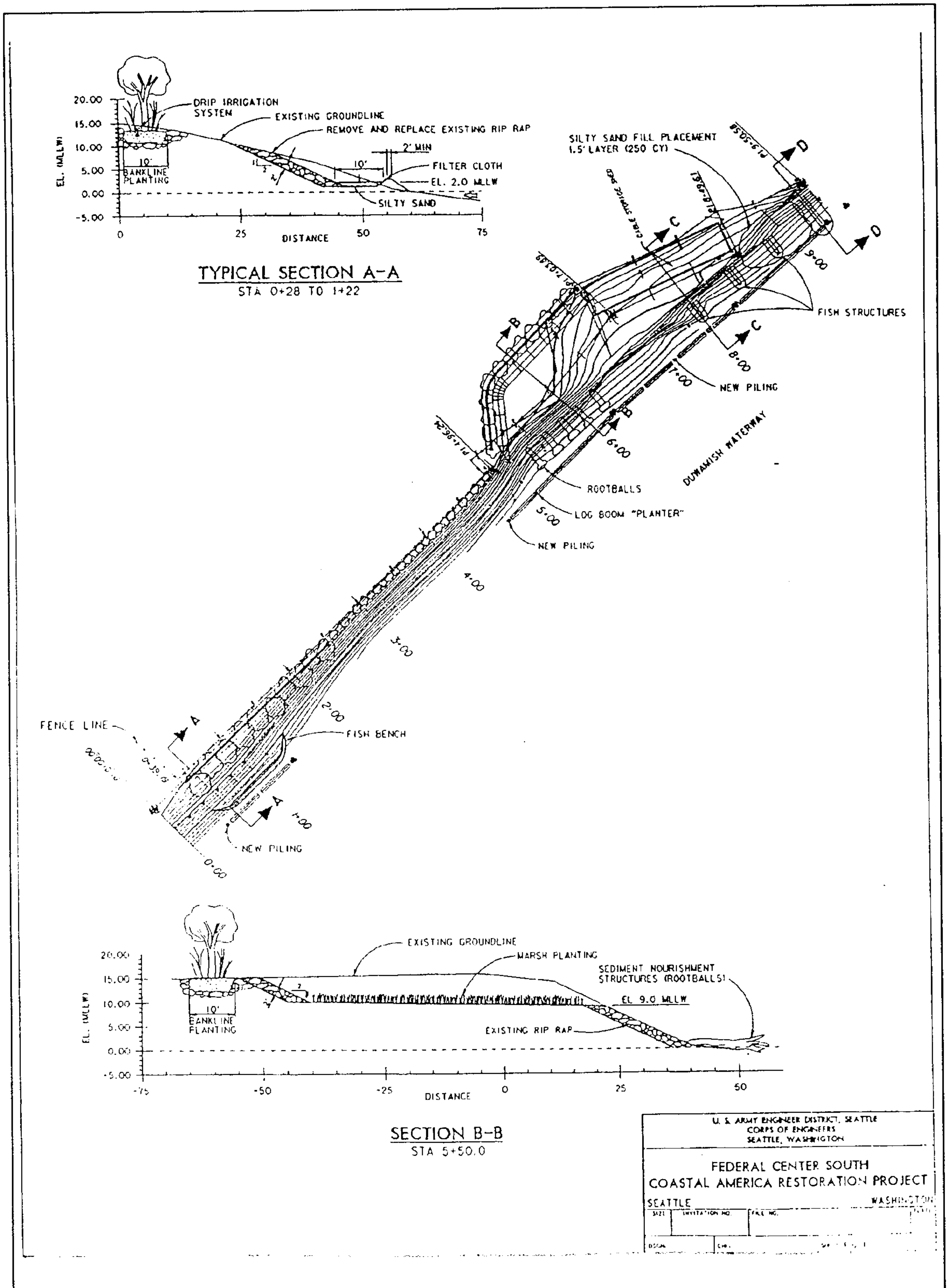
DRIP IRRIGATION SYSTEM
EXISTING GROUNDLINE
REMOVE AND REPLACE EXISTING RIP RAP
2' MIN
FILTER CLOTH
EL. 2.0 MLLW
SILTY SAND
10'
BANKLINE PLANTING
EL. (MLLW)
DISTANCE
TYPICAL SECTION A-A
STA 0+28 TO 1+22
SILTY SAND FILL PLACEMENT 1.5' LAYER (250 CY)
FISH STRUCTURES
NEW PILING
DUWAMISH WATERWAY
ROOTBALLS
LOG BOOM "PLANTER"
FENCE LINE
FISH BENCH
EXISTING GROUNDLINE
MARSH PLANTING
SEDIMENT NOURISHMENT STRUCTURES (ROOTBALLS)
EL 9.0 MLLW
EXISTING RIP RAP
SECTION B-B
STA 5+50.0
U. S. ARMY ENGINEER DISTRICT, SEATTLE
CORPS OF ENGINEERS
SEATTLE, WASHINGTON
FEDERAL CENTER SOUTH
COASTAL AMERICA RESTORATION PROJECT
SEATTLE
WASHINGTON

Figure 1.

project was completed with a budget of $200,000, which does not include the cost of the property. Reference Table 1, for the breakdown of project costs.

Table 1
Federal Center South Coastal America Project Budget

Pre-Project Assessment		**11,700**
Topographic Survey	1,500	
Surface Sediment Grain Size and Composition	100	
Sediment Chemistry Analysis	6,600	
Baseline Studies	3,500	
Engineering and Design		**12,500**
Final Design	2,500	
Plan and Specifications	10,000	
Concentration		**161,000**
Equipment Mobilization	4,500	
Excavation/Regrading	30,000	
Debris Removal/Disposal	30,000	
Substrate Enhancement	4,000	
Slope Protection	7,700	
Bankline Preparation	1,200	
Fish Habitat Bench	16,200	
Plant Acquisition	10,000	
Material, misc.	9,200	
Subtotal	112,800	
Contingency (25%)	28,200	
Contract Administration	20,000	
Post-Construction Monitoring		**15,000**
Sampling and Analysis	15,000	
SITE TOTAL	**200,200**	

One important objective of the project is the analysis of a variety of restoration techniques. Accomplishing this objective will require implementation of a well-designed monitoring plan that provides quantitative information on the habitat quality of restoration sites. To insure the quantitative, comparable nature of data from this monitoring effort, the approach and methodologies prescribed by the Estuarine Habitat Assessment Protocol (Simenstad et al. 1991) will be used. The focus of the monitoring plan will be the measurement of habitat attributes (e.g., prey resources, nesting materials) that provide fish and wildlife species the resources necessary for their survival.

Wetland habitats are, by the very nature, highly dynamic systems. Restored or enhanced habitats take considerable time to reach a dynamic equilibrium. Past experience suggests that a minimum of five years is required before it is possible to determine if projects are beginning to stabilize and perform a sustainable habitat function. Recognizing this, the monitoring plan will be

composed of two components designed to assess short- and long-term habitat goals. First, we will attempt to assess the physical stability of the habitats to determine if they will be able to support the establishment of habitat attributes. Second, we will attempt to ascertain if restoration sites are provided habitat attributes comparable to natural wetland habitats. This monitoring plan began in Spring of 1993 following project construction, and is to be carried out for a duration of ten years.

Several important lessons were learned from this project. The necessity of defining site specific ecological goals for the project while considering what limiting factors where inherent in the landscape was critical. Another lesson was the need to accurately define participants (agency) roles at the beginning of the project. These responsibilities should be formalized in some form of agreement that has buy in at all levels of each organization involved. Finally, restoration in an urban environment is costly, time consuming and opportunities should be taken when presented.

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Environmental Engineering and Wetland Mitigation: The Upper Yazoo Projects, E. A. Dardeau, Jr.,[1] J. Craig Fischenich[1], and Gary L. Young[2]

Abstract

The Upper Yazoo Projects (UYP) is a major flood control effort in the planning phase for the U.S. Army Engineer District, Vicksburg (CELMK). Estimated wetland impacts from this project range between 22,005 and 27,750 acres, depending on the construction alternative. These values include both conversion impacts and hydrologic change, with conversion amounting to about 30 percent. Many of the engineering features (e.g., water control structures) of the UYP are capable of ponding water and could be used to mitigate wetland losses, as well as losses of aquatic (both riverbank structure and floodplain), terrestrial, and waterfowl resources. The U.S. Army Engineer Waterways Experiment Station developed a mitigation strategy that permits CELMK to quantify the advantages and disadvantages of various management and construction alternatives and optimize wetland and other habitat benefits. The approach considers various combinations of project feature operation and land acquisition/management to permit CELMK to select an optimum yet effective least-cost mitigation plan. This paper focuses on the procedures used to mitigate wetland resource impacts in the UYP study and illustrates the importance of applied environmental engineering in wetland mitigation.

Introduction

Currently in the planning phase, the Upper Yazoo Projects (UYP) is a major flood control effort of the U.S. Army Engineer District, Vicksburg (CELMK). The Yazoo Basin covers about 8,900 square miles - 2,300, floodplain ("the Delta") and 6,600, loessial hills (U.S. Army Engineer District, Vicksburg 1989). The project is designed to provide flood control for portions of twelve Mississippi counties. Construction began in 1976 near Yazoo City (southern end of the project) but was halted in 1989 with continuation subject to findings of the UYP Reformulation Study (Dardeau *et al.* 1992). Five water control structures, 55.7 miles of channel enlargement, and 3.8 miles of levees have been completed. The Reformulation Study objectives involved assessment of impacts expected to result from the project, including the constructed portions.

Alternative include up to 167 water control structures (54 of which will be capable of providing 36 impoundments), 52 confined disposal facilities and 47 borrow pits. Project features can be used to mitigate wetland losses as well

[1] U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.
[2] U.S. Army Engineer District, Vicksburg.

as losses of aquatic, wetland and terrestrial resources (Dardeau et al. 1992). One of the objectives of the Reformulation Study was to avoid or reduce environmental impacts. The CELMK requested that the U.S. Army Engineer Waterways Experiment Station (CEWES) to develop a mitigation strategy that permits quantification of the advantages and disadvantages of various management and construction alternatives and optimize wetland and other habitat benefits. The approach used considers various combinations of project feature operation and land acquisition/management to permit CELMK to select an effective least-cost mitigation plan.

Determination of Habitat/Resource Losses

Aquatic and terrestrial losses were quantified using the Habitat Evaluation Procedure (HEP); waterfowl, based on available food and energy requirements; and wetlands, based on functional value acreage. Six construction alternatives were evaluated, ranging from Alternative (Alt) 1, which consists of a system of levees and channels designed to contain the 100-year-frequency flood, to Alt 6, which amounts to only enough channel enlargement necessary to provide an additional floodflow conveyance of 25 percent (at crop damage elevations north of Greenwood, MS). Between Alts 1 and 6 are Alts 2 through 5, representing progressively smaller construction efforts. Estimated losses for each resource would be least for Alt 6 and greatest for Alt 1. Wetland losses expected to occur as a result of the UYP construction range between 22,005 (Alt 6) and 27,750 acres (Alt 1) (Williams, Kleiss, and Clairain 1992). Ideally, compensation for wetland and other resource losses can be made by a prudent combination of land acquisition/reforestation, or ponding regime and management.

Mitigation Approach

An interdisciplinary UYP Study Team was formed to provide environmental expertise in formulating measures to offset habitat losses. The team, consisted of scientists and engineers from CELMK, CEWES, and the U.S. Fish and Wildlife Service (USFWS), developed general and specific habitat-based management approaches and then evaluated the management potential of various project-related features including water control structures, borrow pits, and confined disposal facilities. The approach used in evaluating the project-related determined their cost effectiveness in meeting the objective of 100-percent in-kind compensation for aquatic, terrestrial, waterfowl, and wetland resources.

The Team also selected and evaluated six areas within and adjacent to the project area as potential mitigation sites. These sites were chosen to supplement the compensation offered by project-related features. The rationale used for focusing the mitigation effort at specific sites was to allow for maximum benefits in a systematic ecosystem approach. This approach is not only more environmentally sound but is also more cost-effective, aesthetically appealing,

and reflects a better engineering judgement. With proper planning and coordination, aquatic, terrestrial, waterfowl,and wetland habitat losses can be offset using a common engineering feature or tract of real estate. Each UYP mitigation site was evaluated to determine the potential mitigation value for each habitat category. In addition, observations were made regarding the optimal site use and post-project management.

Wetland Habitat Benefits

Project features. Project features can be operated for wetland provided that they are left open throughout the year (emergencies excepted) to permit interchange of water between the river system and backwater areas. Deliberate ponding on an annual basis from 1 November 15 January for waterfowl will not diminish the wetland value for water-tolerant BLH stands. Only frequently flooded (i.e., at or below the 2-year flood-frequency elevation) fallow or agricultural land planted in BLH species may be claimed for credit. Species of trees planted should be flood-tolerant, mast-producing BLH species. A recommended mix would consist of Nuttall and overcup oaks plus cypress, tupelo, and water hickories. A minimum of 5 years is required for tree establishment before any deliberate ponding is initiated (Williams, Kleiss, and Clairain 1992).

Mitigation sites. At mitigation sites, wetland habitat mitigation can often be accomplished concurrently with terrestrial mitigation. All the real estate acquired should be agricultural land subject to frequent flooding. As with terrestrial habitat mitigation, the land acquired should be plant in mast-bearing, water tolerant BLH species (discussed above).

Multiple mitigation. The real estate requirements for wetland and floodplain aquatic habitat mitigation are nearly identical; wetland sites may be located farther away from main stem river systems than floodplain aquatic sites. Priority, will therefore, be given to floodplain aquatic over wetland habitat for the frequently agricultural lands in closest proximity to the river systems. The difference in the two types of mitigation is that in the former case (wetland mitigation), the land should be reforested, while in the latter (floodplain aquatic), it can either be fallow or reforested, and the gates or the natural system should remain open between March and June to permit fish passage between the main stem streams and the backwater areas.

Method Used

Fischenich, Dardeau, and Parrish (1993) presented some typical management scenarios for the UYP. They discussed the spreadsheet approach that had been developed to calculate values for habitat compensation using various combinations of land-use conversion and site hydrology management. The objective of such an approach was to provide the required compensation while not compromising the engineering objectives of the project. For example,

they pointed out that the loss of 1 acre of BLH was calculated to be have a wetland loss of 1 acre in addition to other losses of aquatic, terrestrial, and waterfowl resources. Other operational scenarios requiring deliberate ponding for periods longer than 2.5 months on an annual basis are possible but would result in BLH losses and (wetland values). Deliberate ponding for extended periods could be conducted on fallow agricultural land at or below the elevation of the 2-year flood frequency elevation for either aquatic or waterfowl benefits. The spreadsheet provides CELMK with a planning tool for making comparisons of the various site and management plan considerations; the objective is to select the plan(s) that affords the needed compensations in the most efficient manner. Economics are considered so that normalized benefit/cost ratios can be generated. Thus, 100-percent in-kind mitigation for wetland and other losses can be accomplished in the most efficient and cost-effective manner.

Response of the Environmental Community

The approach developed for CELMK by Dardeau *et al.* (1992) and discussed by Fischenich, Dardeau, and Parrish (1993) and in this paper has been reviewed by all cooperating agencies and received favorably by the environmental community. Both managers and potential users of the project area support the fact that required habitat compensations will be made using planned project features or tracts of land within or adjacent to the project area while not jeopardizing the engineering objectives of the project. As was pointed out earlier in this paper but cannot be overemphasized, that the rationale of a systematic engineering approach is not only environmentally sound but also more cost-effective, aesthetically appealing, and reflects good engineering judgment. Additionally, post-project management, including all operation and maintenance aspects, is greatly simplified.

Other Applications

There are lessons to be learned from every study. The CELMK/CEWES/USFWS Team realized that no standard formulas exist on how to mitigate. In addition, each element (i.e., aquatic, terrestrial, waterfowl, and wetlands), although intimately familiar with their own procedures, initially had only superficial knowledge of the other resource categories. Therefore, the environmental engineering element had to develop a complete understanding of "the big picture" before offering recommendations for increased efficiency to the process. With the input from the Team members, the environmental engineering element was able to develop a suite of quality plans offering CELMK normalized benefit/cost ratios to aid in the selection of the most optimal plan or plans.

If the efficient plans formulated for the UYP can be developed for such a large project, then such an approach would be applicable to other projects. The lack of precedent guidance has prompted the CEWES to initiate development

of mitigation training for Corps of Engineers personnel faced with this task and thus accelerate the learning process. The training will stress avoidance to the greatest extent possible; however, where mitigation (compensation) is needed, the students will learn a step-by-step process to analyze the situation and determine the most efficient approach to solving their mitigation problems. Lessons learned from the UYP Reformulation Study and other similar endeavors can thus form the basis for classroom instruction and student exercises and offer case studies that exemplify the best approaches to wetland and other resource mitigation that are compatible with project engineering objectives and environmental goals.

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Use of Multiple Options for Establishing Wetland Hydrology: The Manasquan Reservoir Project, Raymond L. Hinkle and Christopher S. Adams, P. E., Woodward-Clyde Consultants, Wayne, New Jersey

Introduction

In the early 1980's, water demand in Monmouth and northern Ocean Counties, New Jersey was estimated to be about 71 million gallons per day (mgd). This was satisfied through a combination of surface water resources and ground water withdrawals. Surface water resources included the Swimming River and Glendola reservoirs, which provided a safe dependable yield of 25 mgd. Ground water withdrawals accounted for the remainder of the daily demand. The majority of this water was supplied by the Englishtown, Wenonah, and Magothy-Raritan Aquifers. As a result of these groundwater withdrawals, aquifers within the area have been severely depleted. Salt water intrusion has occurred within the Kirkwood aquifer at Point Pleasant Beach and the Magothy-Raritan aquifer along the Raritan Bay near Union Beach.

The need for an additional water supply in this region has been recognized since the 1950's. Investigations conducted by the New Jersey Department of Environmental Protection and Energy (NJDEPE) Division of Water Resources identified a site within the townships of Howell and Wall, Monmouth County as the only site in the area with the appropriate topographic characteristics required for reservoir development. The lands where the reservoir is located were acquired by NJDEPE during the 1970s through the 1969 New Jersey Clean Water Bond Act.

An initial Environmental Impact Assessment was conducted for the project by Rutgers, the State University of New Jersey (Rutgers, 1978). This assessment evaluated six alternative facility designs for creating a surface water supply within the Manasquan River watershed. In 1983, the New Jersey Water Supply Authority (NJWSA) commissioned additional engineering and environmental studies, based on a facilities design alternative recommended by the NJDEPE (1982). The selected alternative consisted of a 30 mgd pumped storage reservoir system. The main components of the system included: 1) a 760-acre reservoir on Timber Swamp Brook, an upstream tributary to the Manasquan River; 2) a river skimming intake located along the main channel of the Manasquan River - approximately 2 miles upstream of the Manasquan River Estuary; 3) a 5.5-mile long pipeline; and 4) a water treatment facility near the intake. This alternative provided a significant safe dependable yield while minimizing the adverse environmental effects of previously reviewed alternatives. An analysis of these impacts was required in order to satisfy the requirements of both New Jersey Executive Order 33 and the National Environmental Policy Act (NEPA). The former required the preparation of a Supplemental Environmental Assessment Report for the Manasquan Reservoir

System (MRS) Project (Metcalf & Eddy, Inc. 1985), and the latter required the preparation of Draft and Final Environmental Impact Statements (EISs) by the U.S. Army Corps of Engineers (COE 1986a, 1986b). The COE involvement in the project was triggered by the need for a Department of the Army (DOA) permit authorizing the placement of fill in wetland areas for construction of the dam and dike, and the resultant loss of more than 350 acres of wetlands in the impoundment area.

During the COE's Scoping Process for their EIS the U.S. Fish and Wildlife Service (USF&WS) identified the loss of wetlands as the primary environmental issue associated with issuance of the DOA permit and recommended that an analysis of project impacts on wetlands be conducted by a team of biologists utilizing a version of the USF&WS Habitat Evaluation Procedures (HEP) known as Pennsylvania Modified HEP (PAMHEP). In total, 20 biologists representing state and federal agencies and the NJWSA provided input to the PAMHEP process for the project. The result was a multi-faceted mitigation plan designed to offset unavoidable adverse effects of reservoir construction and operation. Woodward-Clyde Consultants (WCC) prepared the plans and specifications to implement the plan, which were included in the bid documents provided to contractors. Construction associated with the creation of the mitigation wetlands occurred during the period from Spring 1988 to Fall 1989.

Hydrology and Hydraulics

Hydrologic design considerations are critical to the success of a designed wetland. The key requirement for the new emergent wetland areas as determined by the PAMHEP team was that the water depth was to average 2 ft with a range from 1 ft to 3 ft when the reservoir is at full pool. Areas 1 ft to 2 ft deep were planted with emergent wetland species such as American threesquare (*Scirpus americanus*), bur-reed (*Sparganium eurycarpum*), cattail (*Typha latifolia*), and wild rice (*Zizania aquatica*). Areas 3 ft in depth were designated as open water.

In general, several schemes were utilized to design new wetland areas with the required shallow water depth. The first was to raise the ground surface elevation of four (4) finger areas totalling about 80 acres located around the reservoir inundation area. The second was to excavate within upland area adjacent to one of the finger areas to expand the inundation area. The excavated material was used as a source of fill for other elements of the project. Thirdly, upland areas were excavated to intercept the mounded groundwater table created by the reservoir.

About one hundred acres of emergent wetlands were created at the reservoir using these schemes. Since the reservoir system is a pump-storage system, relatively significant fluctuation in the reservoir level is expected. Therefore, it was desirable to have the adjacent wetland areas be hydrologically and hydraulically independent of the main reservoir body when the reservoir level is low but to allow a hydraulic connection when the reservoir is at full pool. A

priority in the final design phase was to accomplish this goal by simple and practical methods. The design of these areas consisted of the following main components:

- Dikes were constructed across the finger areas to separate each area from the main reservoir to maintain water level in the wetland when the water level in the reservoir drops.

- Fill was placed within the finger areas to raise the ground surface and yield the desired water depth (1 ft to 3 ft) with the reservoir at full pool elevation (103.0 ft).

- An outlet consisting of either a box-culvert or a broad-crested spillway with an invert elevation 0.5 ft below the design water level was installed in each dike to maintain the design water levels in the wetland, discharge excess runoff from storm events and to allow exchange of flow from the reservoir into the wetland when the reservoir level is above elevation 102.5 ft.

Exceptions to this general design were made in two cases. A five acre wetland created by excavating to intercept the mounded water table adjacent to the reservoir has no direct connection to it. Rather, water discharges from this wetland through a buried drainage pipe that outlets downstream of the dam. In the second case, a five acre wetland that was developed within a small remnant of the Timber Swamp Brook basin outside of the reservoir footprint discharges to the reservoir via an electrically powered slump pump. This pump transfers water that impounds against the outside slope of a reservoir dike constructed across this basin, thus maintaining the desired water depth in the wetland.

Similar schemes were also utilized for several off-site wetland areas. At several locations studies were conducted to determine the existing ground water conditions and excavations were planned to intercept the groundwater, thereby creating either open water or saturated soil conditions. Emergent species were planted in open water areas while trees and shrubs were planted in saturated soil areas. One offsite area was believed to have been previously used for a gravel washing operation and several small ponds related to these operations (with significantly different water surface elevations) existed on various terraces across the site. The wetland design for this area expanded the existing terracing through excavation and construction of dikes. Three different water surface elevations with a total difference of 12 ft were incorporated into the configuration based on the existing pond elevations and the groundwater conditions. The surface inflow was also significantly increased by routing nearby highway drainage into the wetland.

Water balance studies were conducted for all of the sites to determine whether sufficient water was available to establish the wetland hydrology. The analyses evaluated the direct rainfall and surface inflow from storm events; the normal base flow of streams feeding the wetland; the flow out of the wetland through the spillway or outlet structure; the water lost due to

evapotranspiration; and the water gained or lost by the wetland from or to the ground water table. A water balance analysis was conducted for two particular years; a relatively wet rainfall year and the driest year on record. The analysis evaluated the available water on a daily basis for each of the two model years. Daily rainfall records from a nearby NOAA station were utilized to describe the storm inflow. The results were evaluated according to the average and lowest water surface elevation during the year and the number of days in which the water surface was above the normal pool level (discharging from wetland) and the water surface was at the bottom of the wetland (area dry).

In general, the water balance studies indicated that the wetland areas could be expected to have a positive water balance except during drought conditions. It was decided that low water levels for limited time periods were acceptable since these conditions would occur in natural wetlands. The project site has a net annual precipitation value of about 12 inches which significantly added to the positive water balance. Also, the created wetland areas adjacent to the reservoir benefited from the rise in ground water levels following the reservoir impoundment and the associated reduction in seepage losses through the bottom of the wetland. Therefore, liners were not required for the wetland areas.

Besides the water balance analysis, hydrologic analysis of major storm events were performed to determine the discharge capacity and to evaluate the attenuating effect of the impoundment. The 100-year storm event was selected as the design storm event for appurtenant features of the reservoir system including the wetland areas. State regulations require that post-development flows be equal to or less than pre-development discharges. This requirement applied to the off-site wetland areas. Also, a requirement was imposed on the retention capacity to limit the time period in which the water levels would be higher than the design level. The spillway/outlet structure had to be large enough to discharge stored runoff from the 100-year storm event within seven days.

Acknowledgement

The complex nature of this project required the input from numerous engineers and scientists representing the regulatory agencies and the project sponsor, the NJWSA. The authors wish to thank these individuals, and specifically Messrs. Rocco D. Ricci, Executive Director, Thomas G. Baxter, Chief Engineer, and Richard R. Famularo, MRS Manager, all of the NJWS.

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National Marine Fisheries Service Activities in Coastal Louisiana, Erik Zobrist[1], Rachel Smyk,[1] Greg Miller[1], Timothy Osborn[1], and Rickey Ruebsamen[2]

Introduction

Louisiana contains over 40% of the coastal wetlands in the contiguous United States. These wetlands support the ecological, economic, cultural, aesthetic, and recreational needs of both the State and the nation. They are the source of much of the nation's oil and natural gas, they provide habitat for many species of plants and wildlife, and they serve as a nursery for commercially important species. Louisiana waters alone contributed 44% of the total Gulf of Mexico region fisheries harvest by weight in 1992, generating over $276 million in dockside value (U.S. Department of Commerce, 1993). The natural processes of accretion and erosion that constantly create and destroy these lands have historically existed in relative equilibrium. But human activities have disrupted that equilibrium and now jeopardize the future health of the state's wetlands, and hence the resources that they support. Louisiana's marshes are eroding at an estimated rate of 25 square miles per year, which accounts for roughly 80% of total national wetland loss. Without intervention, the losses within the next 50 years could total 800,000 acres.

The Coastal Wetlands Planning, Protection, and Restoration Act and Task Force

In an effort to reverse the long-term trend of wetland loss, the Louisiana State Legislature passed Act 6 in 1989. The Act created the Coastal Wetlands Trust Fund, which serves as a long-term revenue base for state-sponsored coastal restoration projects. In response to this initiative, the U.S. Congress enacteded the Coastal Wetlands Planning, Protection, and Restoration Act (P.L. 101-646, CWPPRA), requiring the Secretary of the Army to establish the multi-agency Louisiana Coastal Wetlands Conservation and Restoration Task Force (16 U.S.C. 3951 §303 (a)(1)), responsible for: (1) developing a long-term restoration plan for the state's coastal wetlands and (2) developing an annual priority project list for implementing wetland restoration projects. The Task Force includes the following members and their active representatives:

[1] NOAA/NMFS Restoration Center Silver Spring, MD.
[2] NOAA/NMFS Habitat Conservation Division, Baton Rouge, LA.

OFFICIAL TASK FORCE MEMBER	*ACTIVE REPRESENTATIVE*
The Secretary of the Army	The U.S. Corps of Engineers
The Governor of the State of Louisiana	The Executive Assistant for Coastal Activities
The Secretary of the Department of the Interior	The Fish and Wildlife Service
The Secretary of the Department of Agriculture	The Soil Conservation Service
The Secretary of the Department of Commerce	NOAA's National Marine Fisheries Service
The Administrator of the Environmental Protection Agency	The EPA Region VI Administrator

Task Force activities are supported by a federal trust fund of revenues from tax receipts on small engines and other equipment, 70% of which (not to exceed $70 million annually) is available for wetland restoration projects and associated activities in Louisiana. The remaining 30% is available for coastal wetland restoration in other states. CWPPRA mandates that all federal contributions to restoration projects be matched by a state contribution on 75% federal, 25% state cost share basis. Although Louisiana is a Task Force member, it may not participate in wetland project selection nor may the State be the lead sponsor of a project.

The Comprehensive Coastal Wetlands Restoration Plan

The goal of the Louisiana Coastal Wetlands Restoration Plan, as directed by Congress, is to develop a comprehensive approach to restore, and prevent the loss of, coastal wetlands (16 U.S.C. 3953 §303 (b)(2)). CWPPRA directs the Task Force to integrate existing restoration plans for the state's wetlands, such as the Louisiana Comprehensive Coastal Wetlands Feasibility Study prepared by the U.S. Army Corps of Engineers, and the State of Louisiana's Coastal Wetlands Conservation and Restoration Plan, into the CWPPRA Restoration Plan. The Restoration Plan incorporates two strategies to combat wetland loss: offensive approaches seek to build new wetlands using the freshwater and sediments of the Mississippi River and its tributaries; defensive approaches seek to protect existing wetlands through hydrologic restoration, shoreline protection and enhancement, and vegetative plantings.

In order to produce a more site-specific restoration plan, the Task Force created individual restoration plans for each of Louisiana's nine natural hydrologic drainage basins. Within each basin, proposed projects are divided into two categories: (1) projects critical tot he basin-wide restoration, and

(2) supporting alternatives, which compliment the critical projects. Implementation of the critical alternatives within all the basins would restore approximately 152,000 acres of wetlands at a cost of $697 million. Supporting projects would restore 52,000 acres at a cost of $373 million.

Annual Priority Projects Lists and Project Development

In addition to the Restoration Plan, the Tasks Force must annually submit a Project Priority List to Congress. This list identifies projects that will "provide for the long-term conservation of such wetlands and dependent fish and wildlife populations" (16 U.S.C. 3951 §303 (a)(1)). Proposed projects are ranked based on anticipate benefits and cost-effectiveness, with due allowance for small-scale projects necessary to demonstrate the use of techniques or materials for coastal restoration. To date, 29 projects have been selected for funding, at a cost of over $80 million. The National Marine Fisheries service (NMFS) is sponsoring and implementing 5 of these projects, with federal funding totalling over $6 million.

NMFS Involvement in CWPPRA Planning

As a CWPPRA Task Force member, NMFS is responsible for identifying coastal sites to be considered for possible restoration or protection. Priority project development generally involves the following steps: identifying potential sites; gathering preliminary site information; developing project proposals offering possible restoration alternatives with related costs; and conducting wetland value assessments and economic analyses to determine the value of the wetlands and the cost-effectiveness of each project. This effort requires the collaboration of many of the NMFS components as well as additional contractual support. NMFS involvement in CWPPRA activities is coordinated by the Restoration Center (RC), while the NMFS Southeast Regional Office (SERO) oversees the day-to-day activities associated with evaluating potential restoration sites. The Southeast Fisheries Science Center (SEFSC) provides technical and scientific support to the SERO and the RC, and is responsible for the development of restoration monitoring protocols for all NMFS-sponsored CWPRA restoration projects.

Point au Fer Island

Point au Fer Island, located in southwestern Terrebonne Parish approximately twenty-eight miles south of Morgan City, Louisiana, is the site of an active NMFS-sponsored, CWPPRA-funded restoration project. The island is bounded by the Gulf of Mexico to the south, Atchafalaya Bay to the west/northwest, and Four League Bay to the east/northeast. Point au Fer comprises 42,073 acres of emergent intertidal marsh (U.S. Army Corps of Engineers, 1992) which provides habitat for numerous terrestrial and marine species of significant ecological and economic importance, as well as habitat for

endangered and threatened species such as the Southern Bald Eagle, the Brown Pelican, the Kemp's Ridley Sea Turtle, the Arctic Peregrine Falcon, and the Piping Plover (St. Germain, 1993). Smooth cordgrass, *Sparina alterniflora*, dominates the salt water marshes that parallel the gulf coast while marshhay cordgrass, *Spartina patens*, dominates the brackish marshes of the island's interior.

Likes much of coastal Louisiana, Point au Fer has lost wetlands through both natural processes (e.g. subsidence) and human activity. Since 1931, the island has been extensively modified to support human activities such as oil and gas exploration/development, fishing, and hunting. These modifications have accelerated wetlands loss by (1) allowing salt water intrusion into the brackish marshes of the interior island causing mortality of non-salt tolerant plants, (2) reducing the amount of sediment reaching the marsh from the Atchafalaya River and (3) by increasing tidal scour. Consequently, these marsh areas are being converted to open water. Coastal wetlands, such as those being lost on Point au Fer, are critical habitat in the life cycles of 98% of commercially harvested species in the Gulf of Mexico (Hartman, et al., 1993).

Project Description

The Point au Fer project will concentrate on restoring two rapidly degrading areas of the island: in Area 1, two pipeline canals from Mosquito Bayou to the coast of the Gulf of Mexico and the canal linking Mosquito Bay and Bay Castagnier, dredged around 1960, have allowed for rapid salt water intrusion into the brackish marshes of the island; in Area 2 on the western side of the island, approximately 600 yards of beach separating the Gulf of Mexico form an oil and gas access canal near Locust Bayou is also experiencing overwash and salt water intrusion. In August, 1992, Hurricane Andrew exacerbated the problem in both areas. A 2 meter surge opened the mouth of the north-south canal connecting Mosquito Bayou to the Gulf and also breached the beach that separates the access canal from the Gulf.

Preventing or reducing salt water intrusion and reestablishing the natural sediment-laden freshwater flow across Point au Fer island from the Atchafalaya River should diminish human-induced wetland loss and allow for natural coastal migration instead of erosion and conversion to open water. To achieve this, a series of wooden plugs will be constructed in the canals to halt salt water intrusion into the brackish marshes; four canal plugs will be constructed in the pipeline canal between Mosquito Bay and Bay Castagnier, and similarly, two plugs will be constructed in the north-south pipeline canal between Mosquito Bayou and Gulf of Mexico. Plug location is intended to divert fresh water out of the canal and into marshes through natural drainage ways during high flow (flooding) periods in the Archafalaya basin. Furthermore, another existing plug at the seaward end of the north-south canal will be strengthened and the portion of the canal two hundred feet behind the plug will be backfilled, enhancing a total of approximately 3,500 acres of wetlands along

the eastern canals. At the second site, 600 yards of the eroding western shoreline of the island will be enhanced through dredged spoil deposition, thereby protecting 1,900 acres of wetlands. The backfilled area should quickly vegetate and begin to naturally migrate with other gulf beach sediments. The entire project will protect/enhance 5,400 acres of wetlands. The total cost for this project is estimated at $1,100,000, with the 75% federal share equalling $825,000.

Current Status

Project implementation requires detailed site investigation, environmental permitting, and advanced planning, engineering, and design before restoration construction can begin. Currently, NOAA is working with State of Louisiana utilizing a cooperative agreement to implement the project, which will ensure proper cost sharing. Following completion of the final project engineering and design plans, the State will proceed with permitting procedures and obtain land owner approvals. Construction is scheduled to begin in spring, 1994.

Conclusion

This NMFS-sponsored restoration project will fortify the wetlands of Point au Fer Island, enabling them to continue natural barrier island transgression. This project also offers an opportunity for beneficial environmental cooperation between the U.S. Government and the State of Louisiana, and land owners in order to restore the island's threatened coastal habitats. The potential exists for benefits in conjunction with other CWPPRA projects in the area, especially the enhancement of the Atchafalaya Delta. NMFS has gained invaluable restoration planning and implementation experience from this project and will continue to apply this and other fisheries expertise in future efforts to protect and restore Louisiana's coastal wetlands.

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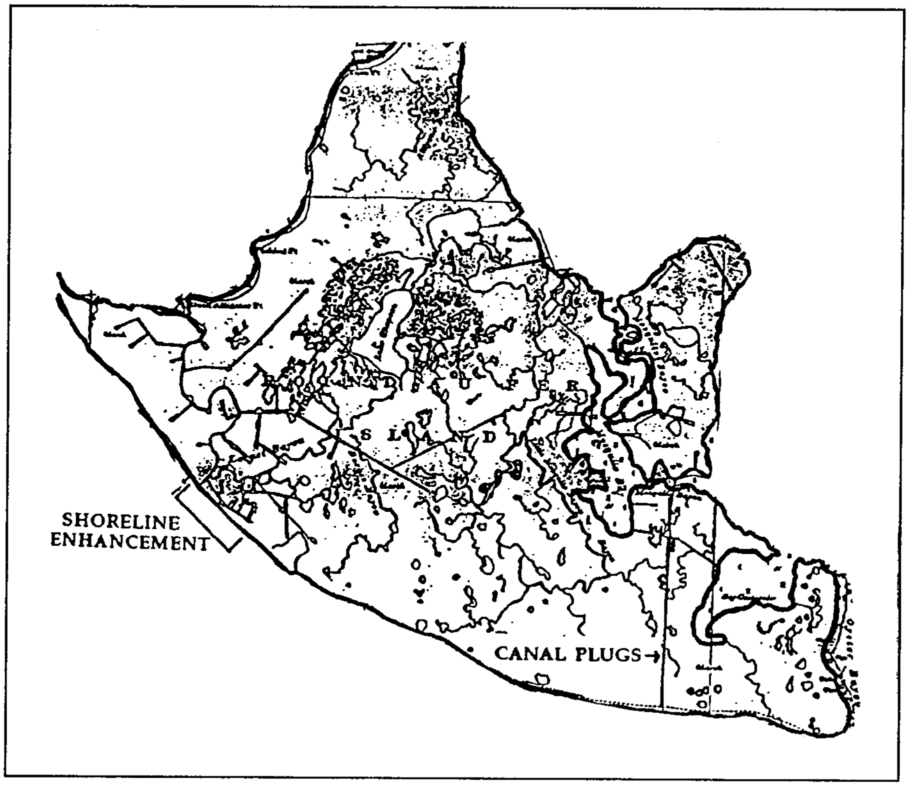


Figure 1. Point Au Fer Island Restoration Project Map

Kawainui Marsh Restoration, James Pennaz, P.E. and Margo Stahl, C.E.P., USACE, Planning Division, Pacific Ocean Division

Abstract

Kawainui Marsh is Hawaii's largest remaining coastal wetland system. Located on the Island of Oahu, at the base of the Koolau Mountains, the marsh contains nationally recognized resources including four species of federally listed endangered waterbirds, and is eligible for listing on the National Register of Historic Places due to its archaeological/cultural significance. The marsh has been spared from development over the years as a result of its designation as a flood control basin in 1966 by the U.S. Army, Corps of Engineers for a flood control project.

On January 1, 1988 the project failed to protect the residents of the community of Kailua when floodwaters moving through the marsh overtopped the project levee and flooded homes. Proposed improvements to the flood control project will require filling of some wetland bordering the project levee. Mitigation for this wetland fill will result in the restoration and creation of wetland in the marsh previously degraded during the earlier project construction. Wetland hydraulic design methods used to meet flood control and marsh restoration requirements will be discussed. The authors discuss planning methods and procedures utilized to bring community and agency groups together to plan the restoration effort.

Introduction

Kawainui Marsh serves as one of the most important ecological, cultural, educational, and recreational resources in the State of Hawaii for residents and non-residents alike, and as an aesthetic buffer to the generally urban character of the rest of the low-lying Kailua area. Interest in wetland protection has become widespread in Hawaii as elsewhere in the country. Hawaii has lost most of its wetlands to development over the years. In recent decades the periphery of Kawainui Marsh has been altered by agricultural and residential development and its waters enriched by years of sewage effluent resulting in a dramatic increase in an exotic floating mat of vegetation. Kawainui Marsh represents one of a small number of these floating marshes in the world (Sasser, Gosselink and Shaffer, 1991). The floating marsh rises and falls with changes in water level. Sewage discharges are now diverted to a deep ocean outfall in the northeast area of Kailua Bay.

History of Kawainui Marsh

Kawainui Marsh is thought to have once been a marine embayment open to the sea. About three thousand years ago the Kailua coastal strand barrier

began to form and the bay became a lagoon. The present day marsh may have remained a lagoon until about five hundred years ago when continual organic filling and isolation from the sea transformed the lagoon into a freshwater marsh. The extent that the early Hawaiians contributed to this infilling is a source of professional debate (Athens and Ward, 1991). The marsh remains freshwater except at the upper end of the discharge channel. The water levels in the marsh normally lie several feet above mean sea level and resist saltwater intrusion.

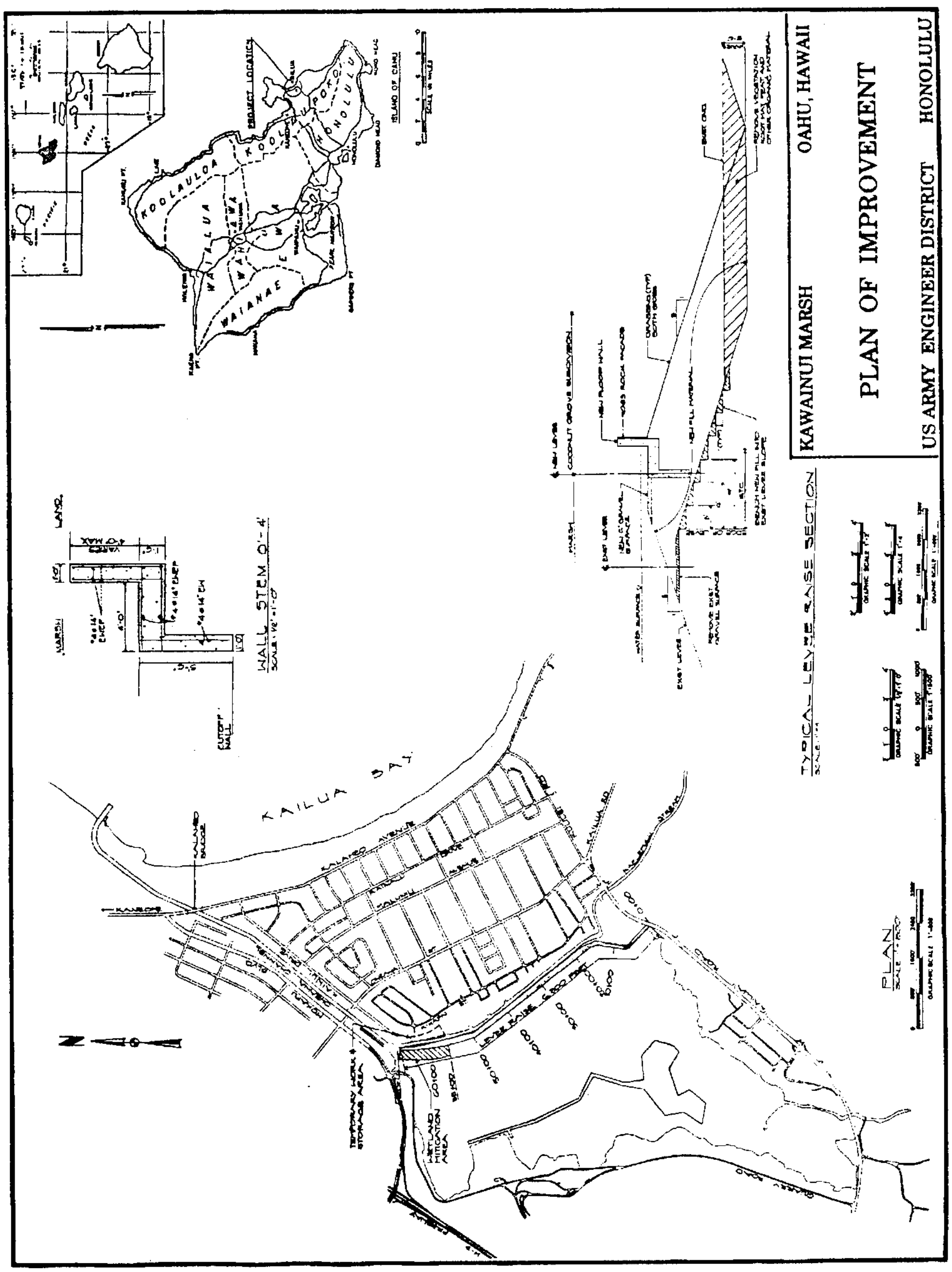
The marsh contains resources of national recognition. It provides habitat to four species of federally listed endangered waterbirds and serves as a migratory pathway for diadromous native stream fish and shrimp (USFWS, 1985). The marsh is believed to be the site of an early Hawaiian fishpond and taro pond culture with a complex series of ponds and terraces covering the upper southern end of the marsh (Drigot and Seto, 1982). Several heiau (Hawaiian platform temple) and other historic sites fringe the boundary of the marsh.

Many community groups and environmental organizations have been interested in the preservation and restoration of the marsh for cultural, ecological, recreational, and aesthetic purposes as well as for flood control. These groups have resisted attempts by various developments to reduce or degrade the marsh and its borders.

Existing Flood Control Project

The existing flood control project includes an earth levee 6,850 feet long with a design crest elevation of 9.5 feet mean sea level and an outlet channel (Oneawa Channel) 9,470 feet long flowing northeasterly from the northern end of the marsh into Kailua Bay (Figure 1). The project was designed to accommodate the Standard Project Flood with a peak inflow to the marsh of 18,100 cubic feet per second (cfs) (4,700 ac-ft volume) and a peak discharge in the Oneawa Channel of 6,750 cfs. Seven hundred and fifty acres of marsh land were acquired by the local sponsor for temporary storage of flood flows as part of the flood control project. The existing project was authorized by the Flood Control Act of 17 May 1950 and was completed in August 1966. On January 1, 1988 (New Years Flood), the project was overtopped by a flood with an estimated peak inflow to the marsh of 19,000 cfs and a volume of 7,775 ac-ft.

The original project design concept was to have the marsh act as a natural flood storage basin. Floods from streams entering the southern end of the marsh would flow to an outlet channel at the northern end. This concept did not work during the New Years Flood because of the larger than design volume of floodwater and because of changed conditions within the marsh resulting from a massive increase in vegetation. The increase in vegetation was caused by discharge of sewage effluent into streams which are upstream of the marsh. Between 1966 and 1988, the marsh was rapidly overgrown by


KAWAINUI MARSH
OAHU, HAWAII
PLAN OF IMPROVEMENT
US ARMY ENGINEER DISTRICT
HONOLULU
KAILUA BAY
WALL STEM 0'-4'
TYPICAL LEVEE RAISE SECTION
PLAN
ISLAND OF OAHU

vegetation making it substandard as a flood control basin and reducing habitat for endangered waterbirds.

Flood Control Planning

During project planning, it became clear that flood control must take into account the effect of the vegetation on flooding, the national significance of the wetland and surrounding area, and the desires of the community, local sponsor, and the State of Hawaii. Computer simulations showed that marsh vegetation would cause floods greater than the 10 year event to accumulate at the southern end of the marsh and eventually overtop the levee. Many alternatives were investigated including the removal of vegetation and sediments within the marsh, pumping stations, water diversions, and various combinations of levee raises. Removal of vegetation and sediments within the marsh was favored by local environmental groups because this alternative would restore the marsh to its former condition and greatly enhance the habitat of endangered waterbirds.

The final plan selected was a combination earth levee raise and concrete floodwall which best met engineering, economic, and environmental concerns. Factors against restoring the marsh to its former condition included potential water quality problems in the ocean receiving waters after the vegetation buffer was removed, vegetation and sediment disposal, long term maintenance of open water areas, and life cycle cost. The Kawainui Marsh Flood Control Project received the U.S. Army, Corps of Engineers Outstanding Planning Achievement Award for 1992.

Engineering Design

The recommended plan consists of a 6,300 foot long, four foot high concrete floodwall on top of a raised levee. The engineering design analysis was enhanced by using the RMA-2V finite element computer model. This model was used for project design because the irregular combination of thick mats of marsh plants (up to three feet thick) and open water areas complicates the prediction of water surface elevations, currents and flows throughout the marsh. Traditional level pool routing methods fail to reproduce the actual hydraulic characteristics of flood events within the marsh. The RMA-2V model was used to explain the hydraulic characteristics of the 1988 flood event and evaluate various alternatives considered including vegetation removal. The model was calibrated using observed depth and duration of levee overtopping from the 1988 flood. Additional calibration data was obtained from an April 1989 event that was monitored by continuous recording stage gages located in the marsh. We recommend use of the RMA-2V computer model for wetland simulations because of the models' ability to simulate entire inflow and outflow hydrographs, marsh porosity and roughness characteristics, and varying water surface elevations.

Environmental Issues

Water quality in Kawainui Marsh is dependent upon a multitude of factors including stream water base flows, stormwater runoff, growth and decay of vegetative material, solar heating, water percolation from springs, and livestock grazing. The marsh serves as both a source and a sink of nutrients. It is one of the primary sources of nutrient and sediment pollution to Kailua Bay according to a study by the University of Hawaii Water Resources Research Center.

Open water areas provide valuable habitat to the endangered waterbirds and enhance water quality in the marsh by enabling sunlight to penetrate. However, the removal of extensive amounts of vegetation to create open water may reduce the water purification services that the marsh presently provides to the receiving waters of Kailua Bay.

Resource Management Plans

The State of Hawaii Coastal Zone Management Program sponsored development of a Resource Management Plan for Kawainui Marsh in 1983. The lead responsibility for implementation of the Plan and for ultimate control over flood control management rests with the State Department of Land and Natural Resources. Advisory committees have helped to update the Plan and the Corps is working closely with the State hoping to assist it in implementing some of the wildlife enhancement aspects of the Plan through funding under Section 1135 of the Water Resources Development Act. The Corps is working closely to ensure that resource management plans are compatible with the flood control function of the Marsh.

Conclusions

Wetland restoration efforts in Kawainui Marsh must take into consideration a number of variables including flood control, water quality, and wildlife habitat. Restoration efforts, therefore, involve an interdisciplinary team working together to accommodate all concerns.

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Design, Construction, and Monitoring of a Created Wetland at the University of Colorado Research Park, Boulder., Lauranne P. Rink,[1] and John T. Windell[2]

Abstract

The University of Colorado Research Park at Boulder constructed a 143 acre research park facility in 1987. A Section 404 permit was obtained in 1988, authorizing modification of 8.8 acres of wetland contingent upon implementation of a compensatory mitigation plan.

The mitigation plan was designed to offset wetland losses incurred through project construction, to provide for creation of a high quality wetland ecosystem, and to provide for improvement of stormwater runoff quality. Additional project objectives identified by the University included creating an educational facility, an academic research complex, and an aesthetic feature that could compliment the adjacent developed areas.

Site grading and the placement of organic dredge was completed in 1988, followed by planting and seeding during the spring of 1989. Thirty-four plant species were planted across four wetland zones.

Semi-annual monitoring was conducted through the 1992 season. Several planted species did not survive while fifty volunteer species were noted. Community composition within each wetland zone has fluctuated with time, with all zones tending towards a higher composition of hydrophytic species.

(Presentation was not made at workshop and paper was not provided.)

[1] Aquatic and Wetland Consultants, Boulder Colorado.
[2] Professor Emeritus University of Colorado, Boulder.

Wetland Hydrology Assessment for Siting and Design, J. Craig Fischenich,[1] J. Scott Franklin,[2] and E. A. Dardeau, Jr.[1]

Abstract

Three basic factors dictate the delineation and function of wetlands: vegetation, soils, and hydrology. Though each of these are important and interdependent, hydrology plays the most significant role. Many of the criteria used to evaluate candidate sites for wetland restoration or creation are based upon site hydrology. Of the 36 major elements used in the Wetland Replacement Evaluation Procedure, for example, 15 are directly related to hydrology, and at least 14 others are indirectly related. The most convenient way to evaluate wetland hydrology is by hydrologic budget analyses. While the basic equation for the hydrologic budget of a wetland can be expressed in very simple terms, its computation can be quite complex. A generalized mathematical modeling approach to the hydrologic budget of wetlands would be of considerable benefit to those involved in the site selection and design of wetlands. This paper discusses the significance of wetland hydrology, describes a generalized procedure for hydrologic budget analyses, and discusses the adaptation of the Wetland Hydrologic Analysis Model to wetland site selection and design. The U.S. Army Engineer Waterways Experiment Station is developing a decision support system to assist planners, engineers, and scientists in the site selection and design of wetlands. A means of incorporating hydrologic budget analyses into this system is proposed.

Background

Widespread public awareness of the importance of wetland ecosystems has led to a proliferation of regulations and policies intended to preserve and protect these valuable resources. As a consequence, a growing need exists for site selection and design guidance for wetland creation, restoration, and enhancement projects. The U.S. Army Engineer Waterways Experiment Station is addressing this need under the Wetland Research Program (WRP). One component of the WRP is the development of a decision support system to assist planners, engineers, and scientists in the site selection and design of wetlands. The Wetland Evaluation Technique for Environmental Restoration (WETER) software system will include modules for wetland function assessment, design criteria, vegetation establishment, soils, geomorphology, and hydrology.

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Importance of Hydrology

Most wetland scientists will agree that hydrology is the most important factor in determining the establishment and maintenance of a wetland. Hydrology dictates many physical and chemical properties of wetlands such as surface area, depth, shoreline irregularity, residence time, nutrient cycling, pH, anoxia, salinity, and sediment characteristics. Biotic components of the wetland ecosystem are likewise affected by hydrology. Plant, animal, insect, and microbial species composition and diversity are all limited by hydrology.

Hydrology should, therefore, play a significant role in the evaluation and selection of sites for wetland creation and restoration projects. For example, of the 36 major elements used in the Wetland Replacement Evaluation Procedure (WREP), 15 are directly related to hydrology and at least 14 others are indirectly related (Bartoldus, Garbisch, and Kraus 1993). This recognized importance of hydrology in wetland function contrasts markedly with the paucity of published research on the subject (Mitsch and Gosselink 1989). The most commonly suggested approach to the evaluation of wetland hydrology is by use of the hydrologic budget.

Hydrologic Budget

The hydrologic budget of a wetland accounts for of all forms of water entering and leaving a wetland during a specified period, with the net difference described as a change in the volume of water stored in the wetland. The basic form for the water budget of a wetland can be expressed as:

$$\Delta S = I - O \tag{1}$$

where

ΔS = Storage Change

I = Inflow

O = Outflow

Although Equation 1 appears unpretentious, computation of the inflow and outflow can be quite complex. Presentation of the variables that make up inflow and outflow helps to illustrate this point. Wetland inflows can be comprised of one or more of the following parameters:

P = Direct precipitation on the wetland impoundment

I_r = Basin runoff by overland flow directly into the wetland

I_s = Streamflow directly into the wetland

I_f = Inflow from adjacent stream flooding

G_i = Wetland inflow from ground water

T_i = Tidal inflows

P_i = Inflow from pumping, diversion, or other artificial source

Wetland outflows can consist of any of the following parameters:

E = Evaporation

T = Transpiration

O_s = Outflow by streams leaving the wetland

O_f = Surface overland outflow due to wetland flooding

G_o = Ground water percolation below the root zone

T_o = Tidal outflows

P_o = Outflow from pumping, diversion, or other artificial source

Figure 1 presents a schematic diagram of a hypothetical wetland system with a complex hydrologic budget. Although ΔS is represented as the volumetric change in surface water, this term could include storage in vascular plants and in the soil within the root zone. Replacing I and O in Equation 1 with the above variables results in the following equation:

$$\Delta S = (P+I_r+I_s+I_f+G_i+T_i+P_i) - (E+T+O_s+O_f+G_o+T_o+P_o) \qquad (2)$$

Solving Equation 2 requires quantification of each of the applicable terms, accomplished in some cases by direct measurement, but more frequently by numerical analysis using modeling techniques and empirical relations. Numerical solution of five or six of the terms in Equation 2 using an equal number of disparate models or data formats can be onerous. A universally applicable modeling approach integrating the necessary tools would vastly simplify this process.

One model, WHAM, utilizes a simplified mass balance approach to estimate the daily hydrologic budget. This model appears to have merit as the basis for a comprehensive analytical tool for the site selection and design of wetlands based upon hydrology. The following sections describe the WHAM and discuss necessary modifications to give it broader application potential.

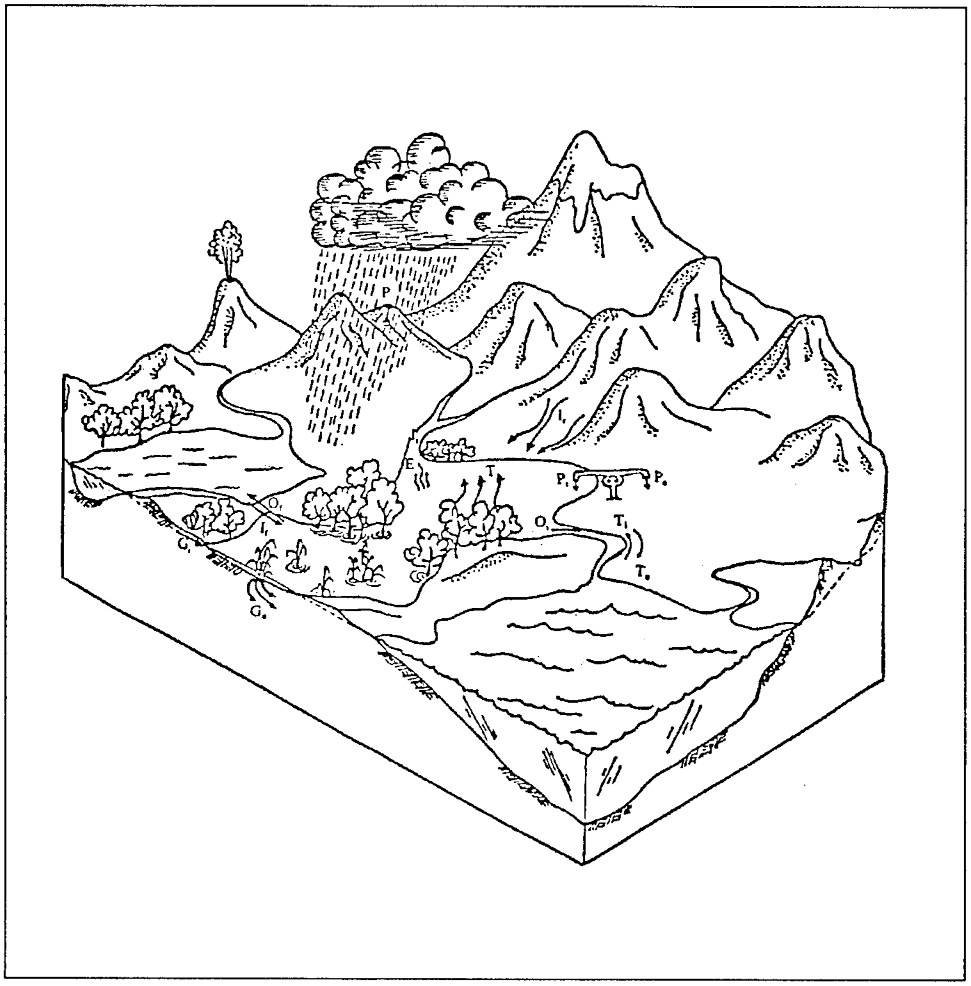

Figure 1. Hydrologic budget parameters for a hypothetical complex wetland

WHAM

Background

The Wetland Hydrologic Analysis Model (WHAM) is an example of a wetland hydrology model produced specifically for the assessment of candidate sites for wetland restoration. It was developed by the Hydrology and Meteorology Section of the U.S. Army Engineer District, Omaha (CEMRO) for the Rainwater Basin Study funded under Section 22 of the Water Resources Development Act of 1974, as amended in 1986. The WHAM was developed after a careful review of existing model technologies indicated that none were suitable for the assessment of site hydrology for depressional wetland systems in Nebraska.

Operation

The WHAM uses a simplified version of the mass balance equation to estimate the hydrologic budget of a wetland on a daily basis for any period of record. Each year is simulated independently on a water year basis, from 1 October to 30 September. Hydrologic budget computation is based upon inflow, precipitation, ground-water inflow, evapotranspiration, seepage rates, pumping, peripheral inflow/outflow, outflow capacity, and initial storage (CEMRO 1991).

Required input for the model includes (1) relations between water surface elevations, surface area, storage volume, outflow capacity, and average depth, (2) watershed drainage area, (3) initial storage, (4) daily historic or generated values for evaporation, inflow, and precipitation, (5) monthly seepage, evapotranspiration factors, outflow capacity factors, pumping capacity and factors, and (6) job control. Optional input includes (1) comments, (2) convergence tolerance, and (3) titles.

The WHAM has options that allow the user to select or suppress various types of output. Output generally consists of various combinations of time, surface area, water surface elevation, storage volume, and average depth, although any of the variables in the mass balance equation can be used. The output can be displayed graphically or in a tabular format, or it may be saved to a plot file. Statistical analyses can be run within WHAM to develop duration curves and to compute minimum, maximum, and mean values of surface area, depths, and constants for seasonal, monthly and annual time periods. The WHAM has the same "look and feel" of many of the HEC computer tools; it uses HECDSS for data storage and output file format and uses the same menu and plot utilities and drivers.

Limitations

The WHAM was developed for depressional wetlands; therefore, the inclusion of tidal influences and river stage in the inflow parameter is cumbersome, although possible. The absence of algorithms for the simulation of watershed runoff requires that this parameter be modeled separately or be based on observed data. Ground-water inflow is neither simulated nor directly accounted for in the WHAM; thus the user may need to adjust the surface inflow, the pumping algorithm or the seepage to account for it (CEMRO 1991).

Discussion

Hydrology, which has been demonstrated to affect a wetland's physical, chemical, and biological character, is probably the single most important factor to be analyzed for wetland enhancement, restoration, creation, and protection projects. Hydrologic analyses are usually conducted for wetland projects.

However, given the diversity of wetland types, functions, climate and physiography, as well as the diversity of the community involved in wetland projects, the approaches used are either too qualitative in nature or are very site specific and consequently have limited general application. A preferred strategy would be one that uses a general-purpose modeling approach to evaluate site hydrology for all conditions in terms directly related to design criteria necessary to achieve a desired function.

Though detailed hydrodynamic analyses are required for water quality-related projects (Hammer 1989), a "simple" hydrologic budget analysis provides the necessary information to evaluate sites and develop designs for most wetland projects. A proposed approach for the evaluation of hydrology within WETER is the development of an object-oriented decision support system that couples mathematical models and empirical data with an underlying database. The computational procedure would be similar to that employed by WHAM but with the capability to deal with all the terms in Equation 2.

The envisioned approach permits the user to select applicable variables in the hydrologic budget and then choose from a palette the desired analytical procedure to solve for each variable. Selection of the procedure could be based upon available data, upon applicability to a specific project, or upon simple preference. For example, the selection options that might be available for I_s would include daily inflow values based upon direct measurement with data stored in a HECDSS file format, a WATSTORE format, or an ASCII file, or daily inflow values based upon model simulations using output from HEC1, SSARR, ARM, FastTABS, etc. Likewise, selection of outflow terms such as P_o would present the user with options depending upon the type of outflow anticipated (overflow weir, pumping, culvert, etc.).

Requisite input files would depend upon the computational procedure selected but would include relations between water surface elevations, surface area, storage volume and depth for all cases. These relations could best be developed using spatial data analysis techniques commonly found in GIS systems. Model output would be consistent regardless of the terms or techniques selected, and would be directly related to design criteria established to meet a particular function(s). In this way, alternative sites could be compared based upon relative attainment of desired function.

One advantage of this type of approach is its inherent flexibility and applicability to a wide range of wetland types and functions. Sensitivity of the results to the analytical procedure used could be readily checked. Because the system would maintain a database independent of the chosen analytical techniques, data exchange among agencies would be simplified, as would be the verification of the analysis by an independent party. The primary drawback is the extensive effort required to integrate the system components and develop the software.

This approach has not been developed further in this paper because the intent is merely to present the concept and solicit input from the user

community. The authors solicit guidance as to the viability of this approach, recommended techniques, preferred operating system and environment, and other pertinent input that would ensure the success of a generalized hydrologic budget assessment system for wetland site selection and design. Cooperative testing and analysis is welcomed.

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The St. Clair County Wetland Mitigation Bank, Mark Ray, Woolpert, Dayton, OH

Abstract

In 1990, Woolpert held a regional wetlands conference in the St. Louis area. Woolpert also performed a St. Clair County Master Land Use Plan. These two activities brought into focus the friction between planned enterprise zones in the County and concentrations of jurisdictional wetlands. This began the coordination and development of a County-wide wetland mitigation system to integrate land use planning with regulatory permits. Phase I was the government agencies and local groups helped form the framework. Comprehensive research of existing banks and associated valuation systems was performed as part of the development of a system that would meet the unique needs of the county and outside agencies. The ongoing Phase II is the implementation of a specific management system, location of feasible mitigation sites in each of four bank branches (watersheds), and preliminary design of pilot project area. The creation of a suitable diversity of managed wetland areas within each branch is being closely coordinated with ongoing development trends and willing landowners. The presentation will outline the history of the development of the mitigation bank, coordination of the effort, and the importance of the technical wetland design factors on the process.

(Paper not provided)

Wetlands Restoration Planning Tool, John N. Hochheimer, Mohammed Lahlou, Chris Rodstrom, Tetra Tech, Inc., Fairfax, VA

Introduction

An important planning step in a wetlands restoration program is the assessment of the wetlands resources on a watershed scale. Wetlands need to be identified within a defined watershed, mapped, and the functional attributes for each wetland determined in order to compare and prioritize wetlands for restoration efforts. Since wetland functions are influenced by changes in the surrounding land use, wetlands restoration planning needs to account for future land use changes, as well as present conditions.

Wetlands and watershed managers would benefit from a simple, easy-to-use tool to assist in landscape-level assessment and prioritization of restoration efforts. In general, at the planning level, limited resources and field data are available. Therefore, the ideal planning tool should use minimal site-specific information while being responsive to management concerns. The Geographical Information System-Watershed Functional Assessment Tool (GIS-WFAT) is being developed to provide resource managers with a tool to integrate wetland functional assessment into a wider framework. GIS-WFAT uses a combination of indices, automatically generated from available georeferenced coverages, to characterize relative functional values for a wetland within a watershed. This paper presents a summary of the progress made in the conceptual development of GIS-WFAT for the assessment and targeting of wetlands for restoration.

GIS-WFAT Development

Wetlands restoration planning with GIS-WFAT is primarily based on interrelationships of wetlands and other land uses within a watershed as illustrated in Figure 1. As hydrology or water quality changes (e.g., by land use or anthropogenic influences) in a watershed, the potential exists for changes to occur in wetlands within the watershed as well. Additionally, uses of wetlands, such as recreational or stormwater treatment, could affect some or all of a wetland's functions. Wetlands restoration projects should be addressed within an integrated framework that examines the contributions of the various impacts, such as watershed changes or wetland use, on the functions of the wetlands.

The conceptual approach for GIS-WFAT is to develop a methodology that allows resource planners to evaluate several aspects of wetlands restoration when evaluating a watershed during the planning phase of a wetlands restoration project. Resource planners need a tool that provides information about the impacts to wetlands from other areas in the watershed and from uses of the wetland. In addition, information about the extent and distribution of wetlands

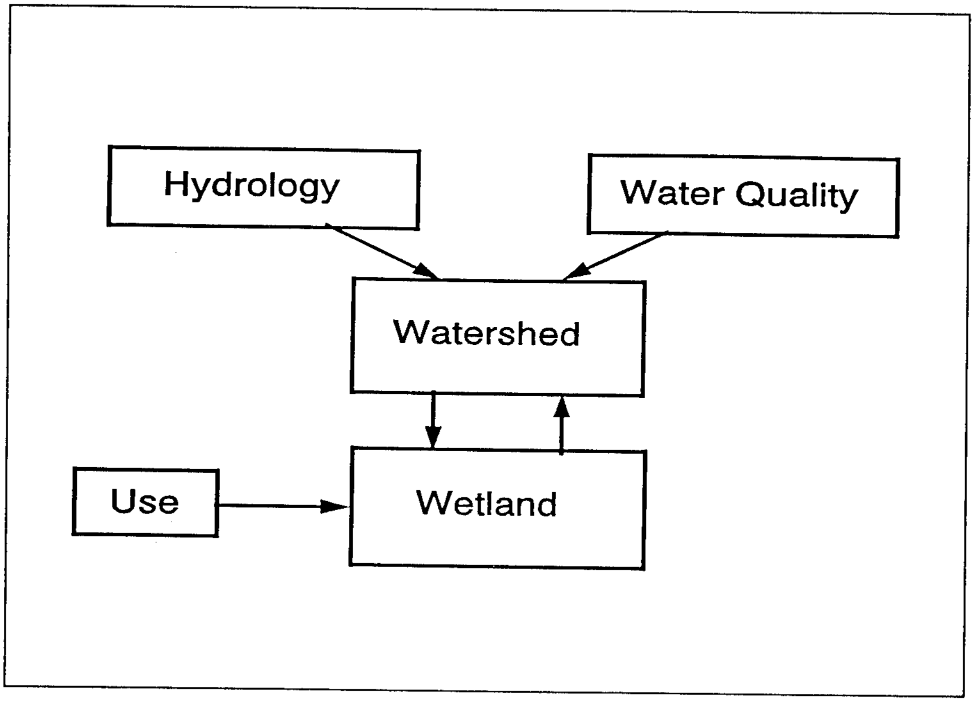

Figure 1. Framework for GIS-WFAT planning-level restoration tool

within the watershed is needed. Often, there are many different possibilities that should be considered when evaluating wetlands within a watershed. For example, one scenario may involve watershed source controls, where practices are implemented in the watershed to control the detrimental effects resulting from various land uses. In this case, restoration efforts might not include any activities within the affected wetland, but only in the watershed. Another scenario might require restoration efforts to take place within the wetland, without the necessity of any controls in the watershed. GIS-WFAT, once fully developed, will allow resource planners to develop a series of "what if" scenarios to determine the best mix of watershed and wetland rehabilitation efforts to restore the desired functionality of targeted wetlands.

GIS-WFAT uses readily available data to derive functional attribute indices for wetlands within a watershed. Available spatial data varies in completeness and resolution across the United States. Some examples of spatial data, suitable for use in a GIS, include satellite images at 10 and 30-meter resolutions; National Wetlands Inventory (NWI) data; roads; streams and shorelines; watersheds boundaries; natural soil series; and land use data. Additional data, either derived from the analysis of these existing data, such as water quality or hydrologic modeling results, digitized from aerial photography, or collected as part of a rapid assessment survey, can be added to the database as needed.

GIS-WFAT is intended for use on a GIS platform to allow the user maximum flexibility in the analysis of wetlands resources within a watershed. With sufficient data in digital form, a GIS is ideal to use for planning wetlands

restoration projects. The data used in the development of GIS-WFAT has sufficient resolution to use in landscape-level planning and screening of watersheds for wetlands restoration. Along with the functional indices, the GIS allows the user to see a composite view of attributes for different areas within the watershed. For example, a base watershed map can be overlain with land use, NWI, and/or soils information and viewed. Additional attributes such as roads, streams, and shorelines can be overlain to determine the relationships of these features with other resources in the watershed. Three-dimensional views of areas within the watershed are also possible and illustrate the topographic features of the watershed.

Derivation of indices

A critical part in the development of GIS-WFAT is derivation of indices to use as indicators describing wetland functions based on available information and at a minimum cost. Problems with developing the indices include the costs associated with data manipulation and collection of field data. The level of detail and accuracy of data available for GIS-WFAT is probably sufficient for planning-level assessments, prioritization for restoration, or impact analysis of wetlands, but may not be sufficient for site-specific, detailed analyses of small areas within a wetland or watershed. A tool like GIS-WFAT offers resource planners and managers a general assessment capability, necessary for watershed or larger scale planning decisions. Watershed scale assessment tools like GIS-WFAT are not intended for detailed, site-specific planning. Thus, with present GIS capabilities and the availability of existing national and local data bases, GIS-WFAT offers a cost-effective approach to wetlands restoration planning.

Presently, indices are being developed to characterize hydrologic, water quality, and habitat functions of wetlands within a watershed. Table 1 shows some of the potential indices that are being developed for GIS-WFAT. Each individual index is derived from readily available data and can be used to describe one or more functional attributes of wetlands within a watershed. The following discussion defines the indices, presents possible data sources and uses for each index, and outlines the rationale behind the indices.

Wetland Area index represents the percentage of the watershed surface area classified as wetlands. In GIS-WFAT, wetland area is calculated from digital land use maps, but can also be determined from NWI data, floodplain maps, or soil surveys. Using a combination of land use and NWI data, GIS-WFAT can produce a table listing the wetlands within a watershed, each wetland area, area as a percent of the total watershed, and type of wetland (as indicated on NWI maps).

Wetland Area index can be used to describe hydrologic, water quality, and habitat functions of wetlands within the watershed. For example, in describing hydrologic functions, wetland area can be combined with overall watershed size, wetland flood storage depth, and average runoff data to determine the

Table 1
Examples of indices developed for GIS-WFAT

Index	Definition	Examples of Restoration Planning Use
Hydrologic		
Wetland Area	Percent of wetland area in watershed	Flood storage capacity, hydraulic characteristics
Fraction of Wetlands Remaining	Wetland area remaining in watershed as a percentage of historical or potential wetlands	Changes in flood storage
Drainage Density	Ratio of stream lengths to watershed area	Amount of riparian transport in watershed
Wetland Patch Size Distribution	Size-frequency distribution of wetland patches	Hydraulic transport
Surface Inflow/ Outflow Ratio	Ratio of surface water volume flowing into a wetland (or area) to the volume of surface water flowing out	Hydraulic residence time, flood storage
Water Quality		
Wetland Area	Percent of wetland area in watershed	Area available for water quality improvement
Drainage Density	Ratio of stream lengths to watershed area	Amount of riparian transport in watershed
Fraction of Wetlands Remaining	Wetland area remaining in watershed as a percentage of historical or potential wetlands	Area available for water quality improvement
Wetland-to-Stream Contiguity	Length of wetland to stream interface	Amount of contact of stream flood waters to wetland
Surface Inflow/ outflow Ratio	Ratio of surface water volume flowing into a wetland (or area) to the volume of surface water flowing out	Loading rates of pollutants into wetlands, water quality improvement function of wetland
Habitat		
Wetland Area	Percent of wetland area in watershed	Area available for habitat
Fraction of Wetlands Remaining	Wetland area remaining in watershed as a percentage of historical or potential wetlands	Area available for habitat
Wetland Patch Size Distribution	Size-frequency distribution of wetland patches	Ability of wetlands in the watershed to support balanced populations of different species
Wetland Area-to-Edge Ratio	Ratio of wetland's area to its perimeter	Amount of interior and edge habitat
Species Richness-Wetland Size Ratio	Ratio of species richness to wetland area	Species richness in a wetland
Species Richness-Wetland Density Ratio	Ratio of species richness to wetland density in the watershed	Species richness in watershed

flood storage functions of a wetland (Simon, Stoerzer, and Watson, 1988). Johnston, Detenbeck, and Niemi (1990) determined that the flood storage capacity in wetlands has a critical threshold of 10 percent of the total watershed area, which means that small wetlands losses in watershed with less than 10 percent wetlands can result in large changes in the flood storage capacity. Jarosewich (1988) discusses a simple methodology to assess the hydraulic character of a wetland for use in wastewater treatment, but can also be used to determine the effects of stormwater runoff on a wetland. Lee and Gosselink (1988) discuss the relationship between water quality and wetland area within a watershed for bottomland hardwood forests. As wetland area decreases in a watershed, the concentrations of pollutants downstream from the watershed are expected to increases exponentially (Lee and Gosselink, 1988). Johnston, Detenbeck, and Niemi (1990) examined many wetlands variables to determine the cumulative effect of wetlands on stream water quality. Wetland area was found to be related to reductions in chloride, lead, and specific conductance (Johnston, Detenbeck, and Niemi, 1990).

Fraction of Wetlands Area Remaining index represents a comparison of present and past wetlands area in the watershed. Past conditions can be obtained from historic aerial photographs and can be digitized for use in the GIS. Similarly, present conditions can be compared to future land use plans. This index is calculated from past, present and future land use maps in GIS-WFAT. The fraction of wetlands remaining, either historically or for future conditions, can be useful in restoration planning. Many wetlands functions have a critical threshold (e.g., flood storage, habitat, water quality functions) that should be considered during planning of restoration projects. Lee and Gosselink (1988) and Harris (1988) present discussions of thresholds for species habitat and the maintenance of balanced indigenous populations. For example, road density in bottomland hardwood forests can be related to the percentage of warbler nests parasitized by alien species. At road densities above approximately 2.5 miles of road per square mile of wetland, the percentage of warbler nests parasitized approaches 100 percent (Harris, 1988).

Drainage density, calculated from total stream length in the watershed divided by the area of the watershed, is another hydrologic functional index. Sources of data for calculating drainage density include NWI data, floodplain and land use maps, and stream location data. Drainage density can be useful to determine the relative amount of riparian transport— the movement of water from upland to the floodplain by nonchannelized overland flow and groundwater flow. Riparian transport tends to be directly related to drainage density and is important in maintaining water quality in local and downstream areas (Brinson, 1988, 1993).

Wetland Patch Size Distribution presents a size-frequency distribution of wetlands within a watershed. GIS-WFAT calculates the size of each wetland within a watershed and determines if the size-frequency distribution fits a log-normal distribution. Lee and Gosselink (1988) suggest that a continuum of wetland sizes ranging from large contiguous tracts interspersed with small patches provides the desired functional attributes of wetlands across the

landscape. By examining the size-frequency distribution of wetlands within a watershed, wetland managers can plan restoration programs that will lead to a more balanced mix of wetland sizes after restoration efforts are complete.

Hydrologic functions of wetlands can also be described with data from hydrologic modeling and streamflow data to form a **Surface Inflow/Outflow Ratio**. This ratio can also be adjusted to include pollutant loadings, from water quality modeling studies, to describe the effects a wetland has on downstream water quality. Brinson (1993) provides a detailed discussion of the hydrologic and water quality benefits of wetlands related to inflow and outflow of water and pollutants. This ratio also provides a measure of the residence time of water in a particular wetland. Pollutant loadings from adjacent land uses, either present or anticipated, can indicate how threatened a wetland is by toxic substances, sedimentation, or eutrophication (Hemond and Benoit, 1988).

The **Wetland to Stream Contiguity** index has been described in Lee and Gosselink (1988) as the length of wetland-to-stream interface divided by twice the stream length. Brinson (1993) discusses the importance of riparian transport through wetlands in nutrient and sediment removal. Wetlands are typically defined as transition zones from uplands to aquatic systems and a measure of the length of these transitional edges also indicates much information about habitat, and to some degree the hydrologic and water quality functions of wetlands.

The **Wetland Area to Edge Ratio** index is a ratio of the total area of each wetland to the length of the outside edge of the wetland. Many species are dependent on either interior habitat or edge habitat and the shape of a wetland (as described by the wetland area to edge ratio) provides an indication of the amount of interior or edge habitat. The connectedness or contiguity of wetlands to form corridors, is important for the movement of animal species, especially larger, wide-ranging animals. GIS-WFAT can determine a measure of connectedness by calculating the distances between wetlands of similar or different type. Brinson (1993) concludes that managers should change goals from restoring or protecting wetland areas to units of length, particularly lengths along streams.

When combined with the number of different species found in a watershed, wetlands area can be used to develop an index of **Species Richness - Wetland Size Ratio** (Weller, 1988). Another index can be derived from the percentage of wetland area, the **Species Richness - Wetland Density Ratio**, which can be used to assess bird habitat loss in a watershed (Weller, 1988).

Restoration Planning with GIS-WFAT

Once a series of indices are developed for a particular wetland function, the next step in the conceptual plan for GIS-WFAT is to determine a way to combine the series of indices to form a composite index for each wetland function. This will give resource planners two options for using GIS-WFAT,

as an interactive tool to perform "what-if" scenario analyses or to determine a "snap-shot" of existing conditions for wetlands within a watershed. The "what-if" scenario analyses are planned to allow a resource manager the capability to change some of the attributes within the watershed to assess a variety of options available for restoring wetlands. Figure 2 outlines a schematic of this conceptual use of GIS-WFAT.

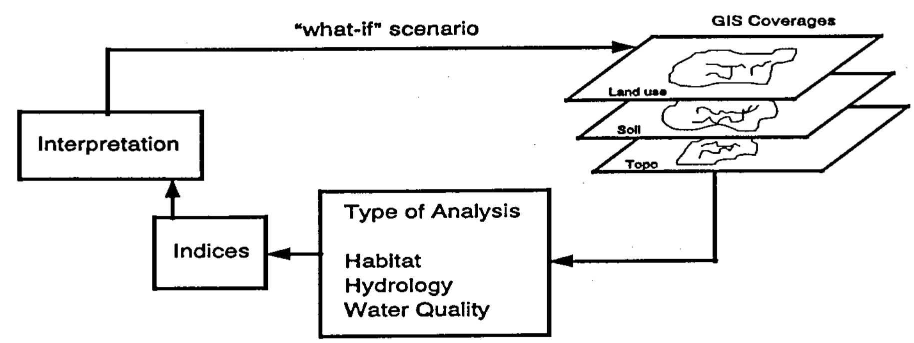

Figure 2. Conceptual use of GIS-WFAT for wetlands restoration

An example of a "what-if" scenario can be made using the index of wetland patch size distribution. The wetland manager using GIS-WFAT first chooses habitat as the type of analysis desired. GIS-WFAT is run for a watershed under present-day conditions and determines a wetland patch size index that is interpreted as an indication of predominantly small, unconnected wetlands within the watershed. The wetland manager desires a more balanced, log-normal distribution of wetland patch size in the watershed and develops several "what-if" scenarios to see how connecting some of the smaller wetlands would improve the size distribution of wetlands within the watershed. Each subsequent run of GIS-WFAT can show the wetlands manager the results of potential changes to the index for wetland patch size distribution. In addition, the manager can look at other indices to determine any potential benefits to other functional attributes or adverse effects from the proposed solutions. Thus, before any individual wetland restoration effort is undertaken, the manager can visually see the changes to the watershed that will occur.

GIS-WFAT could also help a wetlands manager to perform a simpler assessment of the wetlands resources within a watershed by giving the manager a "snap-shot" indication of the present conditions of the resource. If

appropriate indices are combined to form composite index values for a particular wetland function, then the wetlands manager will have to consider only a few index values for a rapid assessment of the resource. A functional composite index will be a combination of individually weighted indices. For example, the composite hydrologic index may combine equally weighted indices of wetland area, drainage density, wetland patch size distribution, and surface inflow/outflow ratio. It is planned for GIS-WFAT to give the user the ability to assign weighing factors to the various indices used to form a composite index, or to use predefined default weights.

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Orwell Lake Restoration Under the Section 1135 Program, Peter J. Fasbender, St. Paul District, Corps of Engineers, St. Paul, MN

Abstract

Orwell Lake is located in west-central Minnesota, Otter Tail County, about 190 miles northwest of St. Paul, Minnesota. The lake basin prior to inundation contained at least 38 prairie pothole wetlands, ranging in size from 1 to 13 acres, interspersed native prairie, and wooded riparian habitat along the Ottertail River. The interspersion and high quality of habitat existing prior to inundation provided valuable habitat for waterfowl and other prairie species. Water level fluctuations have inhibited development of aquatic vegetation in littoral areas of the reservoir which limits the fishery and wildlife use in the vegetation in littoral areas of the reservoir which limits the fishery and wildlife use in the area. It is proposed to: 1) isolate littoral wetlands from the main body to allow for separate water level manipulations, and; 2) restore native prairie areas on adjacent project lands. The goals of this project are to increase the acreage of wetlands, increase the upland nesting reservoir, enhance the habitat value of the existing wetlands, increase the upland nesting habitat quality, and increase the overall value of Orwell Lake and the surrounding area for fish and wildlife. Specific information regarding project planning and design, site selection, and the use of geographic information system will be discussed.

(Presentation was not made at workshop and paper was not provided.)

Wetland Restoration Software System Under Development at WES, Samantha Breeding[1] and Jerry Miller, P.E.[2]

Abstract

A user friendly software system for wetland evaluation and design is being developed by the U.S. Army Engineer Waterways Experiment Station under the Wetland Research Program (WRP). Wetland Evaluation Techniques for Environmental Restoration (WETER) is a decision support system to guide personnel through all phases of wetland restoration. Tools addressing site evaluation, design criteria, hydrology, soils handling, water control structures, and erosion control techniques will be included in the system. A wetland plant database will be included containing information about plant selection, method of vegetating, plant spacing, environmental tolerances, habitat benefits, and planting schedule. Individual modules and tools within the system are designed to be used sequentially or separately. Information from other government agencies, academia, and private industry is being solicited and evaluated for potential inclusion in WETER.

Introduction

In addition to conducting research to develop technology advances for wetland science, WRP experts are working to convert emerging research results into useful products for personnel working with wetlands. Among such products under development is a user friendly software decision support system called "Wetland Evaluation Techniques for Environmental Restoration" or WETER (Miller 1992). An interdisciplinary approach is being used in the development of WETER in an effort to consider the interactions of the various components of the wetland ecosystem.

The foundation for the creation of WETER is Chapter 13 of the Soil Conservation Service National Engineering Field Handbook (SCS 1992) and the design sequence as set forth in the WRP technical note "Design Sequence for Wetlands Restoration and Establishment" (Palermo 1992). Development of WETER is being supplemented by a number of additional sources and from information emerging from the WRP. Input from other government agencies, academia, and private industry is being solicited and reviewed for inclusion in WETER.

The WETER is being developed in the MicroSoft Windows environment. The WETER will consist of individual modules to address the different phases of wetland establishment; planning, design, and monitoring/management. Each

[1] FTN, Associates LTD, Little Rock, AR.
[2] U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

module will contain tools and guidelines pertinent to that particular phase. Reference Figure 1 for an example of the windows for the main menu and the design module.

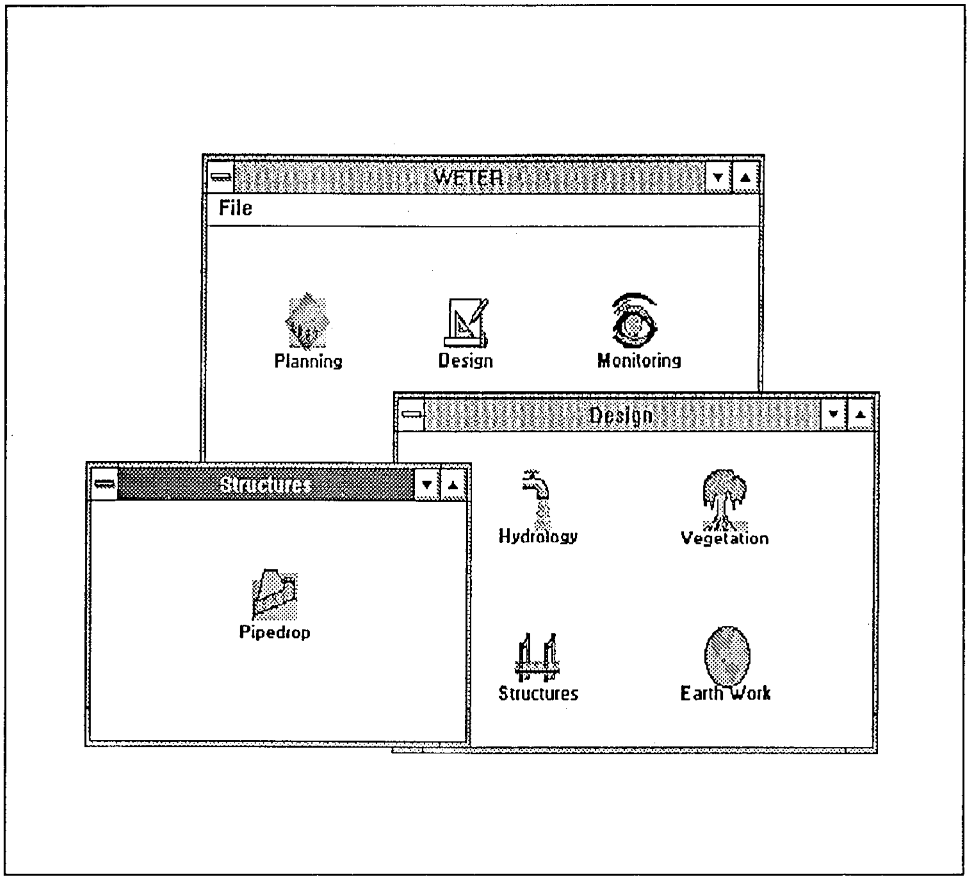

Figure 1. Example of the windows for WETER's main menu and design module

General Outline of Proposed Modules

Planning

In wetland planning, two scenarios are prevalent (Figure 2). In both cases, a site evaluation must be performed. The planning module will include various tools concerning site evaluation and prioritization, selection of compatible functions, conceptual design criteria for primary and secondary functions, and goal setting for success criteria.

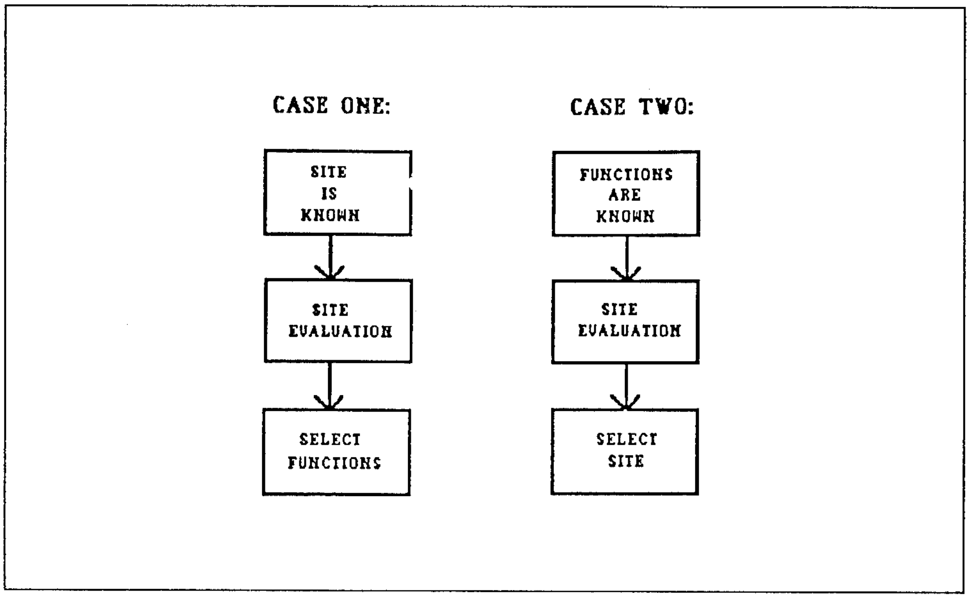

Figure 2. Two scenarios encountered in wetland planning

Design

The design criteria will provide guidance in four major areas: 1) hydrology, 2) geology/soils, 3) structures, and 4)vegetation/biology. Tools for each of these topics will be provided in the design module.

Since there is currently not a model to compute all the aspects of a wetland hydrologic budget analysis, one will be developed. Plans are to design a flexible model that will allow computations of each inflow and outflow parameter applicable to sites under consideration. The model will be compatible with existing programs and file formats.

Some of the proposed issues concerning the substrate soils will include design techniques for substrate fill or excavation, hydraulic fill, design of retention structures, soil handling in wet conditions, and erosion control measures.

Programs for designing water control structures such as pipe drop inlet structures, weirs, and levees will perform the mathematical calculations and generate graphical output, as shown in Figure 3.

Tools under the vegetation module will aid the user in determining the adequacy of existing vegetation, selecting species and planting equipment, and determining the site preparation requirements. An extensive wetland plant database is being developed that will allow selection of plants based on

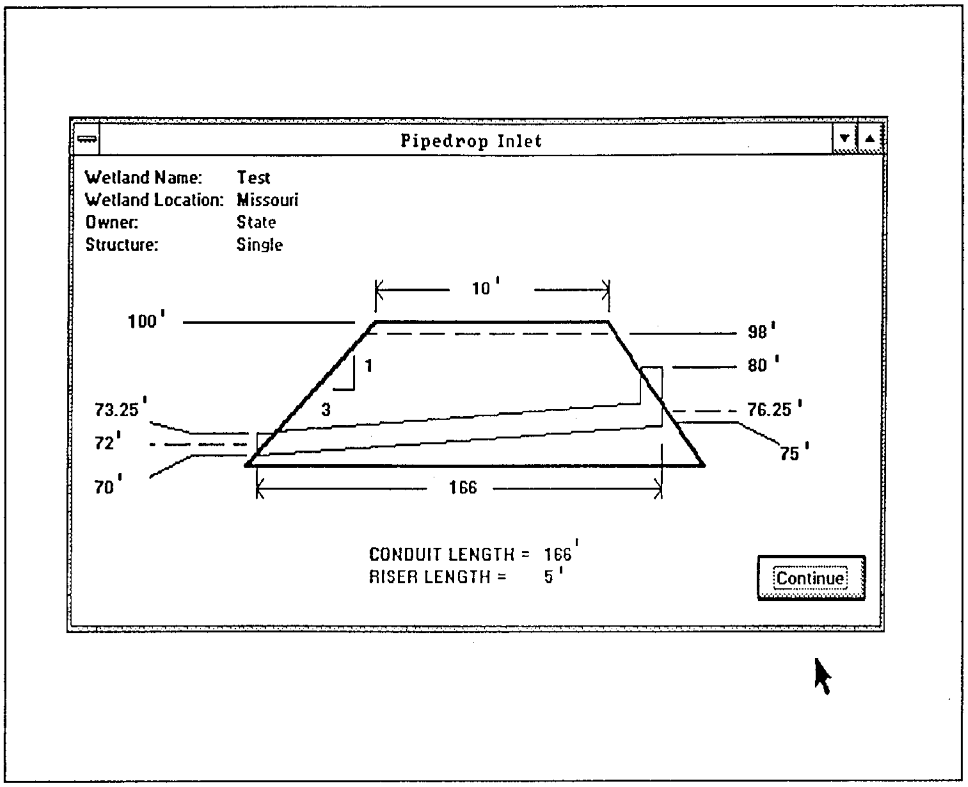

Figure 3. Design graphics for a pipe drop inlet water control structure

geography, type, and environmental tolerances. Approximately forty-five fields of information, such as method of vegetating, planting schedule and spacing, and source of plant material, will be available for each plant listed in the database. Figure 4 depicts an example of the first screen for the database.

Monitoring/Management

Using the baseline conditions and the success criteria previously recorded, the monitoring/management module will assist the user in determining the rate of development and the degree of success. A site visit checklist will be provided as a guide for monitoring a site. This information can be archived for future reference. If the objectives are not being met or if adverse conditions are discovered, suggestions for mid-course corrections will be supplied.

A management plan will need to be developed for each project. The plan will be aimed at realizing the objectives established during the planning phase. Management may include planned procedures to enhance wetland functions during developmental stages of the wetland or active management techniques to correct any potential problems detected during monitoring.

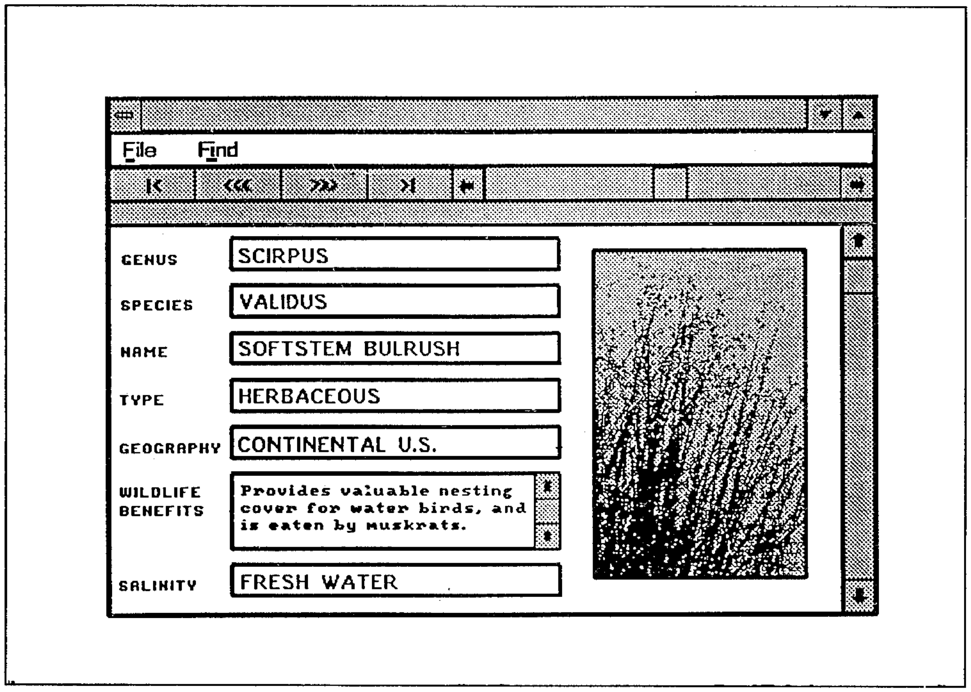

Figure 4. Proposed first screen for vegetation database

Conclusions

The WETER is being developed as a user friendly tool to aid wetland scientists and engineers in wetland restoration. The programs will run on any computer with MS-DOS 5.0 or higher, MicroSoft Windows 3.0 or higher, and an ega, vga, or super vga board. The first version is expected to undergo field review in FY94. The WETER is currently in the early development phase and proposed modules are subject to change. Suggestions, comments, or ideas concerning changes or enhancements should be directed to Craig Fischenich at (601)634-3449.

Acknowledgements

The work described herein is being accomplished by the U.S. Army Corps of Engineers under the Wetlands Research Program. Permission was granted by the Chief of Engineers to publish this information.

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Taking the Bite Out of Wetland Mosquito Problems, Mark Ray, M.S. and Jerry Lang, Ph.D., Woolpert, Dayton, Ohio

Abstract

As a natural component of wetland ecosystems, mosquitoes can become a perceived or a real public annoyance/public health problem. A lack of understanding and communication between wetlands biologists and mosquito abatement personnel has sometimes led to a polarization of viewpoints on the wisdom of wetland mitigation (especially in urban areas) and on proper wetlands management techniques. We propose that an understanding of mosquito biology and use of available control technologies can help wetlands managers minimize mosquito annoyance and mosquito-borne disease threats. A brief overview of the varied life cycles of several important Midwestern mosquito species is integrated into a discussion of wetland design and management techniques for minimizing mosquito production potential. The informed use of bio-rational mosquito control agents such as insect growth regulators and pesticidal pathogens is discussed. Information on mosquito abatement programs in the Midwest and contacts for further information on integrated mosquito management within wetlands are provided.

Introduction

Wetlands pose many dichotomies and paradoxes both technically and politically. Herein lies one person's attraction to them and another's aversion. One question is this. . . "Are wetlands breeding sites for disease vectors or sublime ecosystems providing a myriad of benefits to humans?" The answer can sometimes be both, but, of course, we would prefer to maximize benefits while minimizing health risks. This phenomenon helps explain why the governmental policy pendulum has swung from subsidizing the draining and filling of wetlands to encouraging their preservation and restoration.

Let's take a short walk through history. Up through the 1920s in the Carbondale, Illinois' area (Jackson County), there were over 2,500 cases of malaria a year that resulted in 50 to 100 deaths. In response to this health threat, a multi-agency campaign drained 60 acres of swamps and ponds, lowered a lake to provide a clear water edge, regraded 45 miles of streams, oiled natural breeding sites, stocked ponds and open wells with top minnows, and conducted extensive inspections and educational measures. The resulting number of malaria cases dropped the following year to 19.

Today, the policies of no net loss and preferred on-site mitigation force the issue of creating wetlands in relatively dense human population areas. Various perspectives arise from the history of human relationships to wetlands. Some people would like to see a revival of presettlement acreage of wetlands, while others decry any creation of wetlands.

We propose an understanding and coordination that deals with the reality of the need to conserve wetland resources while considering disease and mosquito annoyance concerns. Many such efforts are occurring between mosquito control practitioners and wetland managers. For the purpose of focus, we center our discussion on conditions in the Midwest. The situations where it is most important to consider mosquito control design features are in the creation of mitigative wetlands in urbanizing settings. Another sensitive area can include zones of higher horse populations because of concerns with equine encephalitis. The development of ecologically responsible, least-toxic mosquito control techniques requires the identification of target species, an understanding of their natural history, and their vector potential.

Midwest mosquito-borne disease concerns

The major mosquito-borne diseases that are current concerns in the Midwest are viral encephalitides. Some distinguishing characteristics of these diseases are summarized here.

LaCrosse Virus. This is a California-group virus that can cause encephalitis in children. There are many unapparent or undiagnosed cases in where either no symptoms appear or only mild "summer flu-like" symptoms occur. Midwestern states exhibit the highest occurrence of this disease. The "Lacrosse belt" follows the edge of the Wisconsin glaciation. The main vector mosquito is *Aedes triseriatus* (a treehole and artificial container breeder). Old tires in shaded or partially shaded areas are favored artificial habitats for *Ae triseriatus*. Reservoir hosts for the virus are small mammals and the mosquito itself. Female mosquitoes can pass the virus to the next generation through infected eggs.

St. Louis Encephalitis Virus. This virus cycles through migratory bird species and is mainly transmitted by *Culex* spp. such as *pipiens*. If the virus builds up to high enough levels in local bird populations, infections can be transmitted to the local human population by *Culex* or other mosquito species. Humans are a dead-end host, and clinical effects are seen mostly in older adults.

Eastern Equine Encephalitis. This virus cycles through various wading bird populations. The main vectors are *Culiseta melanuria* and *Coquillettidia perturbans*. If virus levels build up to where over 10 percent of wading birds are infected, the virus can spill over to other birds like sparrows and pigeons. Spillover can also pass to other mosquitoes that will transmit the virus to horses, pheasants, and humans. This disease can often be fatal in young children.

Life cycles and basic natural history

A very important part of ecologically managing potential mosquito problems is to identify the potential nuisance or disease vector species that might be in your area based on species range and site characteristics. Remember, all mosquitoes are not alike, control strategies can differ greatly. The primary groups of concern are described here by genus.

Anopheles. Females lay single eggs with individual floats. The eggs are laid on the water surface. Anophelines are attracted to clearer waters characterized by floating and/or emergent vegetation. The larvae are air breathers, but they have no breathing siphon so they lie in a horizontal position in the water. Adults exhibit pictured wings and a characteristically upward-angled stance. Female anophelines are potential transmitters of malaria, and they mostly feed on mammalian hosts.

Aedes. Females lay single eggs on moist substrates above waterlines. The larval air sphon is short. *Aedes* mosquitoes occur in a large variety of waters, but especially in temporary impoundments, along floodplains, in pools, and in various containers and plant cavities (phytotelmata). *Aedes* species have mostly mammalian hosts, but some species prefer birds and amphibians.

Culex. Egg rafts of about 100 eggs each are laid on the water surface. *Culex* larvae have long air siphons. *Culex* are especially attracted to highly enriched (eutrophic) waters. The larvae feed more in the benthic zone. Many *Culex* mosquitoes prefer avian hosts.

Coquillettidia. Eggs are laid in clusters under leaves of floating vegetation. Larvae have modified siphons to obtain oxygen from submerged stems of aquatic plants. These mosquitoes have avian and mammalian hosts and are especially common in freshwater marshes in the Great Lakes region.

Psorophora. These mosquitoes are floodwater breeders that scatter eggs on moist surfaces like *Aedes*; some are predaceous on other floodwater mosquitoes. Also, like *Aedes vexans* and *Coquillettidia perturbans*, they are aggressive human biters.

The nuisance factor

Aside from disease potential, several factors contribute to some mosquito species being a more likely target for specific control based on their relative annoyance to humans. This is one area where applied ecology can be put to work to cool down or avoid local political outcries.

Some species can be a problem because of the sheer numbers typically produced. In the Midwest, a primary example would be floodwater mosquitoes such as *Aedes vexans*. Typical breeding locations can affect the

probability for human contact. *Culex* and *Aedes* are the genera that most often reproduce abundantly in urban settings.

Flight range variations can reduce or exacerbate the proximal nuisance distance between mosquito and human population concentrations. Some species can move many miles along river and stream corridors from breeding sites to populated areas (e.g., *Aedes vexans*). Many others will not range in any numbers beyond 0.5 to 1 mile from the breeding location. Some *Aedes* like *stimulans* and other woodland pool breeders are only problems when people actually enter their habitat.

Host preference is important too. Some species are very generalistic and others fairly specific. Many *Culex* will feed on birds if given a choice. It is possible to have relatively high numbers of a species not preferring human hosts in an area and not have a high level of complaints. On the other hand, relatively low numbers of *Psorophora* can cause a lot of discomfort to humans. Peak biting periods can also affect potential for human interaction. All mosquitoes demonstrate periodicity in biting patterns. Most peak during crepuscular (dawn/dusk) periods. Some will bite in daylight and sun, others in daylight only in the shade, some only at night, etc.

Lastly, but sometimes making all the difference, is human attitudes. By and large, these vary by geography and may range from tacit acceptance of large numbers of mosquitoes as a part of life to calls into the mayor's office at the first bite (Hammer, 1992).

Mosquito Control Through Wetland Management

When the need arises to restore or create wetlands where mosquito production has a moderate to high probability to cause adverse societal reactions, it may be advisable to consider carefully what might be planned into the wetland design and management plans from the outset that could help minimize potential problems. Some ideas are discussed here and organized in Table 1.

Soil factors

Especially where nuisance floodwater species (e.g., *Aedes vexans*, *Psorophora*) are a problem, design and management should minimize exposure of bare soil areas that may provide egg-laying sites in cracked soil and flotsam detritus. A spring exposure may allow deposition of eggs that release discrete hatchings throughout the summer at each drawdown. Spring flooding and fall drawdowns after frost at the end of the mosquito season are favorably coincidental to both plant management and floodwater mosquito control. If both spring and fall drawdowns are desired as part of migratory shorebird management, try to amend the site with a sandier soil that reduces soil cracking with out limiting preferred shorebird food invertebrates on the flats.

Table 1
Ecological Management Summary for Control of Mosquitoes[1]

Taxon	Primary Health Concern	Habitat Requirements	Life Cycle	Targeted Management
Aedes/Psorophora	Aggressive human biters, no major viruses.	Flood pools and other temporary water sources. Often in urban settings	Female lay eggs on detritus, in cracks in soils above high water level. Eggs hatch in water with low dissolved oxygen.	· Maximize flow through · Minimize soil-exposing drawdowns during times of high adult mosquito populations · Raise water levels · Maximize oxygenation
Woodland *Aedes*	*A. triseriatus* is vector of LaCrosse Encephalitis virus	Seasonal woodland pools, tree holes, and artificial containers	Females lay eggs on leaf litter and other periodically-inundated detritus. Small mammals are hosts.	· Eliminate incidental water containers. Not a threat in typical created wetland · Use BTI early in spring on ephemeral pools
Culex pipiens	St. Louis Encephalitis virus	Any waters high in organic matter Often in urban settings	Females lay egg rafts on water surface. Larvae are mostly bottom feeders. Adults prefer avian hosts.	· Reduce nutrient inputs · Discourage wading bird hosts · Cover water surface with floating plants
Coquillettidia perturbans	Eastern Equine Encephalitis virus	Vascular aquatic plants Abundant in freshwater marshes around Great Lakes	Eggs on undersides of floating leaves. Larvae and pupae use plant stems as sources of oxygen. Avian and mammalian hosts.	· Drawdowns early in season strand larvae on plants (thrive in constant water level) · Manage vegetation (reduce/eliminate cattails)
Anopheles ssp.	Malaria	Cleaner, sunlit waters with some floating vegetation Good water quality	Eggs laid singly on water surface Larvae are surface feeders	· Drawdowns strand larvae and expose them to increased wave action and predators · Maximize windfetch, but shade water where possible · BTI not as effective use methoprene

[1] Characterization and integrated control of specific problems requires the assistance of a mosquito control professional.

Hydrological factors

Eliminating incidental microreservoirs can be important in controlling the woodland *Aedes* group. Natural or artificial containers can sometimes elude the eye as a potential source of large numbers of mosquitoes. Good housekeeping when creating or managing wetland areas can be very important. Even a water-filled foot print can produce hundreds of *Aedes, Psorophora,* or *Culex* in less than a week. Avoid leaving tire ruts in wetlands by using mats and tracked equipment during final grading. Try to avoid the production of stagnant water pockets in your wetlands. Sometimes water control structures and pipes, whether associated with the wetland or not, can turn out to be the source of nuisance swarms. Perhaps even the poorly drained rooftops of the building construction that required adjacent mitigation could be the cause of complaints from people who may mistakenly point their fingers at the wetland.

The ability to develop a water balance is important to any wetland creation. Multi-seasonal drawdown and flooding capability is also essential to many mosquito control techniques. If a steady, controllable water source (i.e., permanent surface or groundwater inputs) is not available at a high-risk mitigation site, it would be better to avoid that site. The ability to provide a flow-through system with a relatively short replacement time assists in increasing oxygenation and lowering nutrient concentrations, which may both be important in mosquito control. When longer retention time is important to filtering capacity and water quality goals of the project, some of those same benefits can be gained through aeration with low-head fountains or bubble racks. These mechanical measures are common in wetlands designed to treat wastewater, but they can also benefit urban area mitigations by disturbing the water surface to discourage siphon-breathing larvae and water-surface oviposition.

The ability to regulate stream or sheet flow inputs of nutrients into the mitigative wetland can be important. Water quality management is often a problem in developed or agricultural contexts because of proximal sources of sewage, fertilizer, or livestock wastes. *Culex* are attracted by the products of organic decomposition in anaerobic settings (e.g., hydrogen sulfide) and also to volatile organics (e.g., phenols). One rule is to avoid nutrient-laden stream inputs or surrounding landscapes prone to produce nutrient-laden runoff. Another is to install filter basins or forebays at inlets. Transformation of nutrients and consequent mosquito control can be concentrated at these "mini-wetlands" adjacent to the larger wetland. Buffer strips and careful adjacent land use and drainage design can help control runoff sources. Just as it is important to identify target mosquito species to effectively control them, it is also important to chemically analyze input waters to help trace sources and institute controls.

Biological factors

The careful selection and control of certain plant species and their abundance can be a key part of limiting the microhabitats that can determine the

relative abundance of many mosquito species. Disperse extensive floating mats of *Polyrhiza*, *Spirodela*, or *Lemna* unless *Culex* (the egg raft layer) is a problem. Controlled burning or mechanical removal of cattails may also be advisable. The maintenance of an interspersion of open water with vegetation is often a design element of water quality functions or wildlife management. This same practice can help in maintaining water flow, oxygenation, and moderated nutrient levels to minimize mosquitos. Interspersion can also help provide predaceous beetles and fish access to all life stages of mosquitoes. Collins and Resh (1989) have published a well referenced "Guidelines for the Ecological Control of Mosquitoes in Non-tidal Wetlands of the San Francisco Bay Area." One of the most insightful portions of this study is a practical assessment of the habitat value of common plants, especially the relative proclivity of different species to provide an abundance of long-duration positive menisci that serve as refugia for suspended larvae at the point where plant stems leave the water. Plants that produce negative menisci, or dimples, do not provide microcavities to safely harbor larvae from their predators. Although this study dealt with western plants, these same properties apply, at least in part, to eastern congeners. Some of the taxa that provide the least hospitable environment to mosquitoes while being useful for other reasons are *Alisma*, *Sagittaria*, and *Isoetes*. Some of the worst for providing protective niches and being overall pest species are *Typha*, *Lythrum*, and *Myriophyllum*. Another method of vegetative control may include the use of natural larvicide applications. The seeds of *Capsella bursa-pastoris*, when broadcast on the water surface, develop a mucilaginous halo that entraps larvae.

The management of other animal components of a wetland should be considered. The typical encouragement of native dabbling waterfowl is useful in mosquito control. Ducks can help maintain paths through vegetation to increase interspersion. *Potomageton pectinatus* provides refugia for larvae and their zoo-and phytoplankton food species. *Potomageton* is also a preferred food of many dabblers' so a natural-targeted control presents itself. Though often planted for ducks, *Potomageton* should be avoided in urbanizing risk areas to minimize both mosquitoes and waterfowl in developing settings. Filamentous algae, another prime refugia, can be controlled by introducing grass carp, but introducing vegetation grazers can frustrate other goals for the wetland. A more direct approach is to encourage predators. Maintenance of 50 percent open water in wetlands has been shown to benefit predaceous beetles and odonates and significantly reduce mosquito populations (Batzer and Resh, 1992). The introduction of mosquitofish (*Gambusia*) is a time-honored practice in many areas of the country. A native, hardy and aggressive mosquito-eating analog for the Midwest is the green sunfish (*Lepomis cyanellus*). Crayfish are often recommended as part of a mosquito-control program, but their habitat requirements and grazing habits can also frustrate functional designs of a wetland mitigation.

A developing field is the introduction of mosquito pathogens and insect growth regulators as an augmentation to design and management considerations, if necessary. These pathogens and regulators are also used in natural wetland areas. *Bacillus thuringiensis israeliensis* (BTI) is a highly specific

bacterial insecticide. When mosquito larvae ingest the endotoxin-containing spores, their guts swell and burst. Another bio-rational control agent is methoprene (trade name Altosid), which is an insect growth regulator. This preparation works by arresting larval instar development. The Minneapolis-St. Paul Metropolitan Mosquito Control District is sponsoring long-term studies of the impact of methoprene and BTI on invertebrates, birds, amphibians, and other ecosystem components. The work is being reviewed by an independent scientific review panel and preliminary results have been encouraging in that target mosquito populations can be reduced without significant direct or indirect impacts to non-targets (Bob Sjogren, personal communication). The Saginaw Mosquito Control Commission is cooperating with other groups in the integration of various water management techniques and limited use of BTI (Sally Wagoner, personal communication). The Ohio Department of Natural Resources (ODNR) is dealing with the management of wetlands in wildlife management and restoration areas that are in Amish country where eastern equine encephalitis has been a problem. ODNR is conducting survey and control and allowing limited mosquito larviciding (Pat Ruble, personal communication).

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Criteria for Wetland Restoration Site Selections Case Studies in Elliott and Commencement Bays in Puget Sound, Washington, Robert C. Clark, Jr., NOAA Restoration Center Northwest, Seattle, Washington

Abstract

Criteria for evaluating potential wetland restoration sites have been developed by the Natural Resource Damage Assessment (CERCLA) trustees working with potential responsible parties (PRPs) and applied to two different urban estuary systems in Puget Sound, Washington. Elliott Bay (Seattle) and the Lower Duwamish River was studied as part of a $24 million habitat development and sediment remediation consent decree and Commencement Bay (Tacoma) was inventoried for sites as part of a pre-settlement joint trustee/PRP restoration plan. Individual criteria included: site size, proximity to estuarine resources and to historical and on-going pollution, status of forthcoming source control, potential for enhancing injured natural resources, land ownership, connectivity to existing natural resource critical zones and corridors, public access, potential for public participation/education, cost effectiveness, nearby land use (present and planned). These criteria were grouped into high, medium, and low priorities and then each was further ranked into three categories by a team of locally knowledgeable scientists, resource managers, land use specialists, and government environmental representatives. Once consensus was reached by the local experts, the resulting general groupings were taken to public information workshops for further input from the public, business and local governmental communities. The criteria were similar for the two sites but the matrix was flexible enough to allow for regional and local variations and can serve as a template for evaluating a collection of prospective wetlands restoration sites.

Introduction

As Natural Resource Damage Assessment (NRDA) settlements are being reached for toxic chemical impacts on urban wetlands under Superfund (Comprehensive Environmental Response, Compensation, and Liability Act of 1980: CERCLA), NRDA trustees in the Pacific Northwest have had to develop objectives, goals, and criteria for selecting suitable wetland restoration sites and projects. Two major urban environments in Puget Sound are the subjects of extensive planning and implementation for restoration: Seattle's Elliott Bay and the heavily industrialized Lower Duwamish River and Tacoma's Commencement Bay nearshore tideflats and waterways, including the Puyallup River. Each location has unique requirements but because they form a part of the larger Puget Sound estuary and because many of the NRDA trustees serve in both locations, major approaches are similar.

A habitat development or restoration (and integrated sediment remediation) program has been initiated in Elliott Bay as part of a six-year, $24 million settlement with the City of Seattle and Metro, the local waste water treatment entity, for damages attributed to their storm drain discharges and combined sewer overflows. The resulting consent decree sets forth the general parameters for spending $5 million for habitat development on top of up to $5 million for real property. The land forms have changed significantly in the region since the 1850's with nearly 98% of the productive intertidal habitats of the original Duwamish River mouth being lost to historical natural resource use and being replaced by industrial and marine commerce uses. The original meandering river now follows a straight dredged waterway for its last six miles. Spawning salmon still use the system but the resource is being continually placed under stress from loss of habitat, loss of prey organisms, and the release of chemical contaminants.

Commencement Bay has been inventoried for possible restoration sites as part of a pre-settlement, joint NRDA trustee/potential responsible parties (PRPs) bay-wide restoration plan. A draft consent decree with one PRP for NRDA liability involves a six-year, $12 million settlement plus land considerations; negotiations are ongoing with other PRPs to settle their potential liabilities in other parts of Commencement Bay. The original broad tidal flat of the mouth of the salmon-rich Puyallup River has been diked, dredged, and filled until only 2% of the original intertidal mudflats and saltmarshes remain undisturbed.

The NRDA trustees include the Federal Government (U.S. Department of Commerce through the National Oceanic and Atmospheric Administration and the U.S. Department of the Interior through the Fish and Wildlife Service and Bureau of Indian Affairs), the State Government (Washington State Departments of Ecology [lead], Fisheries, Wildlife, and Natural Resources), and Indian Tribal Governments (Muckleshoot Indian Tribe and Suquamish Indian Tribe in Elliott Bay and Muckleshoot Indian Tribe and the Puyallup Tribe of Indians in Commencement Bay). These trustees working together and with consensus have developed with the PRPs a set of ecosystem-based goals, objectives, and criteria for establishing restoration projects using NRDA settlement funds.

Goals and Objectives

The overall goal is to provide a net gain in the function and diversity of habitat types, species, and the habitat attributes on which they depend in the existing urban ecosystems. The fact that the existing aquatic ecosystems cannot be returned to a pristine condition is recognized; however, it is possible and desirable to provide increases in habitat quantity and quality. Where natural resources may not recover without efforts above and where it is necessary to go beyond regulatory requirements for contaminant source control and sediment cleanup, active habitat restoration will be implemented. These goals meet the statutory objective of restoring, replacing, or acquiring the equivalent

resources injured or destroyed as a result of the release of hazardous substances.

Specific objectives were developed by local technical working groups of experts as a means to define desirable functioning, sustainable, and healthy ecosystems for the industrialized urban estuaries where selected habitats and species of fish and wildlife can be demonstrably and predictably enhanced beyond existing conditions. A series of integrated projects are being pursued to allow systems to provide habitat attributes which support the ecological processes characteristic of a healthy ecosystem, support a diversity of habitats and species historically indigenous to the estuary, and to be environmentally and economically sustainable. To the greatest extent possible, a landscape ecology approach to restoration is being pursued which includes consideration of location within the estuary as it influences the habitat attributes of a site as well as the promotion of ecological connections, both between shoreline sites and with nearby upland habitats. In general, if functioning and diverse habitats similar to lost natural habitats are now provided, the appropriate species will follow. This is to be accomplished through preserving existing threatened habitats while enhancing those surviving and creating new ones.

Experience from previous local restoration projects is being used to refine new projects and to plan subsequent undertakings, Many projects will undoubtedly involve phased implementation. Each project is evaluated both on its own merits and on how it fulfills the overall needs of the ecosystem by providing diversity and connectivity between other interrelated habitats. Opportunities for innovative design concepts and engineering techniques for habitat development are being investigated and assessed before being applied to larger scale projects. Also creative solutions to leverage additional funds and non-monetary resources, such as land, construction and long-term stewardship, are encouraged.

Restoration projects will need performance criteria and will be monitored to evaluate their effectiveness in providing the desired increases in habitat attributes as part of a comprehensive planning. Estuarine wetlands restoration in the Pacific Northwest is in its infancy and we are learning as we progress with more projects. Results from project monitoring will be considered before application on a larger scale and may be used for mid-course corrections, where possible. Habitat restoration project will be protected through suitable legal agreements for ecologically significant periods of time, often stated as "in perpetuity."

The restoration efforts require public involvement and participation by incorporating public input into restoration planning, by fostering greater understanding and appreciation of the natural resources of the urban aquatic ecosystems, and by gaining broad public support in design, monitoring, and long-term stewardship of the sites through frequent educational and public involvement activities (Open Houses, public information meetings, hearings, talks, displays, school outreach programs, stewardship and special interest groups). Direct public access at restoration sites should be guided by a

concern for controlling disturbance and disruption of habitats but can often be accomplished by enlightened educational efforts.

Inventory of Potential Sites

In order to establish an holistic restoration concept into which specific projects can be integrated to maximize natural resource enhancement and minimize costs, potential sites need to be identified through review of existing information. A basic assumption underlying both these case studies was to look for vacant or underutilized shoreline since little natural intertidal habitat still survives. Site visits were conducted and photographic documentation was made. Each potential site was evaluated as to consistency of potential site restoration with the functional goals and landscape approach. Site characteristics were described (existing habitats, shoreline type, land use, ownership, history, location, presence of or proximity to apparent contamination, potential relationship to injured trust resources) and listed on a matrix evaluation form.

Site Assessment Criteria

Individual site assessment criteria were established and then separately evaluated by a team of locally knowledgeable scientists, resource managers, land use specialists, and government environmental experts. The criteria addressed site size, proximity to estuarine resources and to historic and on-going pollution, status of forthcoming source control, potential for enhancing injured natural resources, land ownership, connectivity to existing critical natural resource zones and corridors, public access, potential for public participation and education, cost effectiveness, and current and future land use (Table 1). Criteria for Elliott Bay were grouped into high, medium and low priority. For Commencement Bay, criteria were identified as "required" (sites that presently did not meet these three required criteria were screened out) and "preferred" (high, medium, or low).

Each of the two bays had its own set of restrictive considerations into which the individual restoration planning matrix had to fit; however, the end results were basically the same — all sites were grouped into smaller subsets of sites having the highest potential for successful restoration. Once these site groupings were obtained by the expert/consensus teams, the results were taken to public information workshops for further input from the public, business, and local governmental communities. This iterative method of evaluation using a matrix of criteria should be flexible enough to allow regional and local variations so as to serve as a template for evaluating a collection of prospective wetland restoration sites in other parts of the country.

Table 1
Criteria for Site Selection

Elliott Bay	Commencement Bay
High-Priority Criteria	*Required Criteria*
Size. Amount of potential restorable habitat area (subtidal, intertidal, riparian) *Guideline:* Greater than 2 acres is regarded beneficial. *Rationale:* Larger sites will allow greater heterogeneity of habitat attributes. NRDA restoration activities on larger sites that would not be restored through other processes (*i.e.*, §404 mitigation, noncompensatory restoration).	Availability. Is or can be made available. *Guideline:* Sites without substantial structures or pavement are. *Rationale:* Demolition and site preparation costs are reduced. ation projects will seldom displace existing commercial uses.
Distance from Contamination. Location of existing or potential sources of contamination relative to the proposed restoration site	Source Control is or will be sufficient. Source control is sufficient if an environmental audit or similar report demonstrates that the site has limited potential for recontamination
Guideline: If a site contains contaminated sediment or soil or is in a mixing zone of an ongoing source, it should be rated as disadvantaged (Elliott Bay) or screened out (Comm. Bay). *Rationale:* Restoration activities should not be undertaken at sites with a high risk of contaminating target organisms until sources are controlled or sites cleaned up.	
Addressed Injury. Extent to which restoration activities at a proposed site address injury to trust resources	Provides Functional Benefits to Injured Natural Resource.
Guideline: Sites benefiting injured trust resources will be preferred. Site restoration may include restoration and preservation or enhancement of physical or biological conditions. *Rationale:* Priority should be placed upon activities that directly relate to species of concern under the consent decree (Elliott Bay) or for historical trust organisms (Comm. Bay).	
	Preferred Criteria - High Importance
Location. Physical location of potential restoration within the estuarine ecosystem	Location
Guideline: If location of the site in the system ensures that the habitat will be used or are located in an ecologically critical area of the estuary, the site should receive a higher rating than if this were not the case. *Rationale:* Habitat types and their location within the estuary should be determined based on principles of landscape ecology — sites that are necessary for increasing populations of target species.	
Medium-Priority Criteria	
Proximity to Other Habitats. Potential for target resources to use other habitats with connection to the potential restoration site	Functional Connection with Existing or Potential Habitat Sites
Guideline: A surface-water connection to wetland or riparian habitats is considered beneficial. *Rationale:* Potential restoration sites adjacent or proximate to existing habitat areas will provide greater habitat value. Sites that offer a potential connection to streams, riparian corridors or freshwater wetlands are especially important.	

(Continued)

Table 1 (Concluded)	
Elliott Bay	**Commencement Bay**
Adjacent Land Use. Nature and condition of surrounding land use.	**Separation from (Sources of Contamination) or Environmental Disturbances**
Guideline: Sites where existing land uses of adjacent properties do not have an adverse impact on aquatic resources are scored higher. *Rationale:* Noise, bright lights or otherwise disturbing human activities and land uses may reduce habitat value and use of restoration sites.	
Engineering Cost/Likelihood of Success Site attributes impacting cost and likelihood for success include elevation, currents/deposition, wave energy, existing habitat value, topography, and shoreline condition. *Guideline:* Sites where habitat restoration goals can be met with less change (*e.g.,* less earth-work, less shoreline alteration, less engineering, less cost) and low maintenance or human intervention over time should receive a higher score. *Rationale:* Enhancing a site which already provided some beneficial habitat functions is regarded as more certain of success (and usually more economical) than creating habitat where none exists. It is recognized that sites are part of a dynamic system and will change, and that the use of natural processes and successions and principles of adaptive management will enable restoration goals to be met.	Sustainability and Cost-effectiveness
Proximity to Public Facilities. Extent to which potential restoration sites are geographically and physically associated with existing public facilities, such as parks and fishing piers in Elliott Bay *Guideline:* Meeting this condition established by the Consent Decree should result in a higher score. *Rationale:* Consistency with the Consent Decree.	
Low-Priority Criteria	*Preferred Criteria - Medium Importance*
Ownership. Fee-title owner(s) of potential site	Ownership and Management
Guideline: Public ownership is regarded as beneficial. Sites where ownership and management promotes restoration sooner and in perpetuity receive a higher score. *Rationale:* It may be desirable to restore sites already in public ownership to avoid complex land purchases.	
Adjacent Land Use (Potential). Potential land use included consideration of such attributes as shoreline designation, zoning, comprehensive or project-specific planning	Compatibility with Probable Land and Shoreline Uses, Plans, and Designations
Guideline: If potential land use would result in adverse impacts to aquatic resources targeted for restoration, the site would be downgraded. *Rationale:* Noise, bright lights or otherwise disturbing human activities and land uses may reduce habitat value and use of restoration site.	
	Size. Moderate weight is given to sites that form larger area of contiguous habitat.
	Natural Recovery. Moderate weight is given to sites that may recover naturally in a specific time period.
	Preferred Criteria - Low Importance
Public Access. Physical ability of public to access or view the restoration site	Public Access.
Guideline: Meeting this condition should be considered beneficial. *Rationale:* Sites that would accommodate nonintrusive public access might provide educational and recreational amenities while promoting long-term stewardship.	

Ecological Engineering Considerations in Constructing Wetlands for Surface Mine Reclamation, Robert B. Atkinson,[1] David H. Jones,[2] and John Cairns, Jr.[1,2]

Introduction

The Surface Mining Control and Reclamation Act (SMCRA, P.L. 95-87) was enacted in 1977. Although the act has been highly successful in reducing much of the environmental damage associated with surface mining for coal, several authors have noted its limitations. Wyngaard (1985) characterized reclamation strategies associated with the act as vague. The issue of handling water on a site, even without metal or pH problems, is no exception. Any impoundment that is "permanent" is "prohibited unless authorized by the regulatory authority" (Sec. 816.49a). Reclamation associated with area mining, e.g., in the midwestern United States, has begun to include wetlands that are designed to maximize wildlife habitat functions (Klimstra and Nawrot 1985). Contour mining in mountainous regions presents a different opportunity for wetland construction and has not received as much attention.

The mountainous, western portion of Virginia contains only approximately 6% of the state's wetland acreage. Unlike area mining, contour mining does not result in extensive flat land. However, on benches at mid to higher elevations, there is often sufficient surface water flow to support wetlands that may be formed in small depressions (less than 0.5 ha, and less than 1.0-m deep). These areas on pre-law (i.e. SMCRA) sites often contain wetlands that formed accidentally. Many perform wildlife functions described in the literature (Turner and Fowler 1981). Accidental wetlands associated with natural drainageways across benches may perform additional ecological services such as flood flow desynchronization and sediment trapping. Flood amelioration may be provided by the morphometry, including wide basins of low slope, and accumulated organic matter.

In Virginia, the Division of Mined Land Reclamation (DMLR) has regulatory language allowing "small depressions" (Sec. 480-03-19.816.102), but no definitions or engineering designs are provided. Current rules require an approved revision to the permit if wetlands are to be left on a permitted site. Other factors limiting wetland construction in surface mine reclamation in the region are discussed by Atkinson (in press). This paper presents an analysis of communities within accidental wetlands to yield engineering design specifications for the construction of wetlands. The specifications will provide design guidance to operators and monitoring criteria for DMLR. It is hoped that the

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technical and other limitations will be removed so that wetlands can be included as a component of a compatible post mining land use.

Methods

Four sites with a total of 14 accidental wetlands were selected for study. Parallel transects with permanent plots at 5-m intervals were established in each wetland, and vegetative analyses were conducted in the 1992 and 1993 growing seasons. Relative cover and relative frequency of each species were calculated for each wetland and were summed to derive a modified importance value (Mueller-Dombois and Ellenberg 1974).

Mean elevation per plot was calculated from three elevation estimates taken with a level. Permanent hydrology stakes were established and monitored biweekly through the 1992 growing season, and hydrology stake elevation was also taken with the level. Water level and elevation data at each site were compared in order to calculate mean depth per plot. Three soil cores were taken at each community within each wetland, and depth of sediment and particle size analysis were measured for each horizon. Vegetation, soil, and hydrology data were analyzed to determine if each site satisfied all three parameters of wetlands in the 1989 federal manual (Federal Interagency Committee for Wetland Delineation 1989).

Results

A total of 94 species were associated with the 14 accidental wetlands in 1992 (Atkinson and Cairns, in press). Species were assigned to indicator categories described in Reed (1988; Table 1), and the majority included obligate wetland species (26) and facultative wetland species (22). An obligate wetland species dominated community occurred at depths greater than 25 cm and included *Typha spp.*, *Juncus acuminatus*, *Potamogeton americanus*, *Eleocharis obtusa*, and *Sparganium americanum*. Of the 226 wetland plots, 83 were in obligate wetlands communities. The mean number of species per plot was 2.52 ± 1.48, and the mean depth of this community was 49.67 ± 17.46 cm.

A facultative wetland species dominated community occurred at depths shallower than 25 cm deep, and included *Scirpus cyperinus*, *Juncus effusus*, *Salix nigra*, *Impatiens capensis*, and *Bidens aristosa*. Of the 226 wetland plots, 143 were in facultative wetland communities. The mean number of species per plot was 5.43 ± 2.52, and the mean depth of this community was 1.44 ± 19.52 cm.

Soils in both communities in all 14 accidental wetland sites were classified as hydric and possessed indicators including chroma of 1 and oxidized rhizospheres. All 14 sites appeared to have trapped sediment. Sediment depth ranged from a minimum of 5-cm deep in some facultative wetland

Table 1
Indicator categories and probability of a plant species occurring in a wetland (Reed 1988)

Indicator Category	Wetland Frequency
Obligate wetland	>99%
Facultative wetland	67-99%
Facultative	34-66%
Facultative upland	1-33%
Obligate upland	<1%

communities to a maximum of 50-cm deep in some obligate wetland communities. Accidental wetland age ranged from 12 to 25 years, but other factors, e.g., remaining in the watershed, more strongly influenced sediment depth. Approximate mean dimensions for the accidental wetlands was 30 m x 60 m, and the mean slope was 2.39 cm per meter.

Discussion

Construction of demonstration wetlands

Potential coal companies were identified, and six sites were selected based on the following water quality parameters: pH 6-9, iron <3.0 mg/l, and manganese <2.0 mg/l. Negotiations were successfully conducted with three coal companies for construction of three wetlands in series at each site. Wetland placement was selected based on proximity to an intermittent stream, i.e., natural drainageway, that originated in the adjacent, undisturbed forest (Figure 1). Rationale for construction is given in Atkinson (in press). Mucking of the second wetland in each series is recommended. Although such wetlands are likely to become shallower over time, the construction in series should allow for some protection for wetlands downstream in the series and provide maximum ecological services during the critical early years of reclamation.

Wetland design was originally based on selected attributes of accidental wetlands. Further refinement in design was added in order to comply with the DMLR interpretation of small depression; in particular, a maximum depth of 1.2 m and a maximum fill of 0.6 m were agreed upon. Since the average size is 0.1 hectare, e.g., 20 m x 50 m, the shallow depth allows for very gradual slope, e.g., $\leq$2.0 cm per meter (Figure 2). Depending on hydrology, these dimensions should provide roughly equal area for both the obligate wetland and the facultative wetland communities. In this way, the maximum habitat diversity can be achieved and still qualify as a shallow depression.

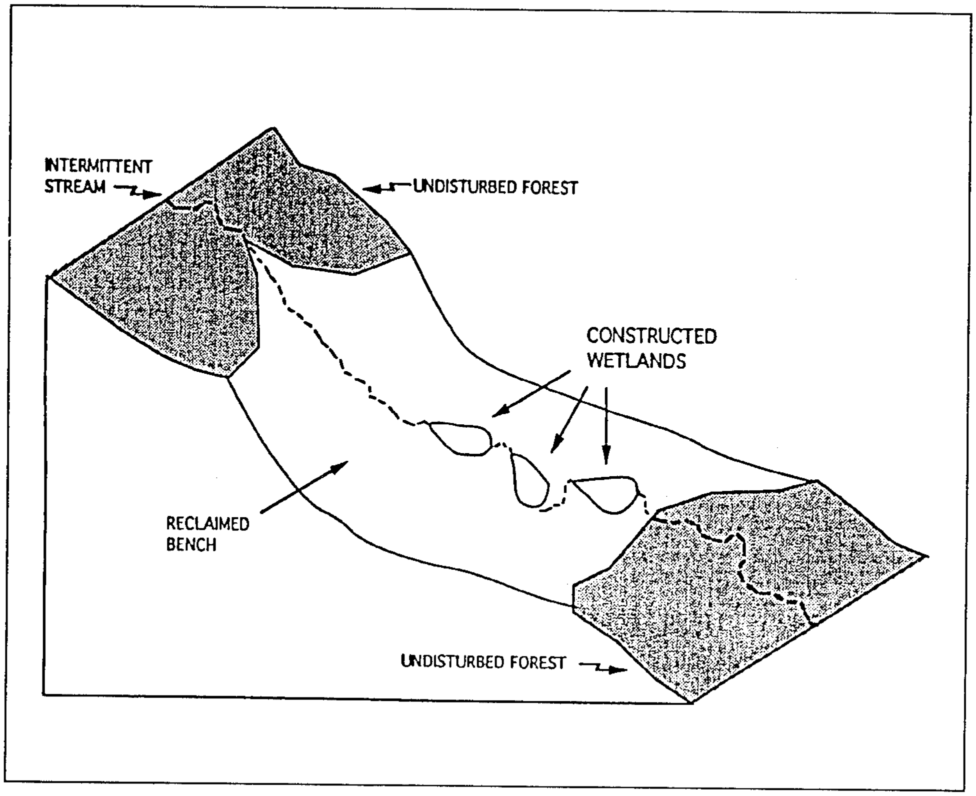

Figure 1. Orientation and idealized layout for constructed wetlands in a reclaimed surface mine landscape

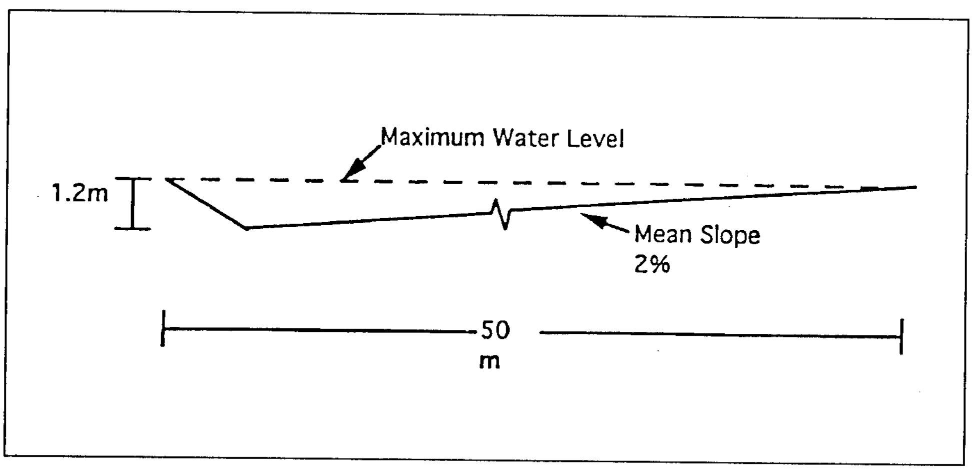

Figure 2. Sectional diagram (in valley-axial direction) of a constructed wetland

Ecological services

In addition to the goal of providing a net increase in wetland acreage, the design specifications described herein are to yield ecological services, including wildlife habitat, sediment retention, and flood flow desynchronization. Accidental wetlands surveyed were shown to perform both wildlife habitat and sediment retention services and, although not quantified, are believed to reduce flood peaks and provide low flow maintenance.

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Engineering Description and Collection of Wetland Soil Properties, Lawrence D. Johnson and Roy E. Leach, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS

Abstract

Engineering properties such as strength, compressibility, and permeability influence the critical soil processes that govern the performance of a wetland. Approximate engineering properties may be evaluated from the engineering description with some information on mass properties such as density, void ratio, and water content. Engineering properties for the final design, restoration, construction, and maintenance of wetlands may be provided from results of a detailed site evaluation and soil survey with field and laboratory soil tests.

The engineering description, besides assisting with the determination of engineering properties, is useful as an aid to identify wetland soils and to delineate wetland areas. The thrust of the engineering description should be to indicate the types of soil from the texture; i.e., relative proportion of sizes, shape, and hardness of soil particles. Soft, compressible, fine-grained soil such as organic silt, organic clay, normally consolidated plastic clay, peat or muck are undesirable for supporting construction equipment, embankments, roads, or other structures. Sands, gravels, and some low plasticity clays usually provide the best construction materials.

This report describes the evaluation of the engineering description by field expedient and laboratory tests. Field expedient tests including but not limited to breaking, dilatancy, roll, color, and odor provide an approximate engineering description by observation and with portable equipment. Laboratory tests evaluating the liquid limit, plasticity index, and particle size distribution are used with the United Soil Classification System (USCS) to accurately identify the soils and combined with results of hardness and density tests, the results can provide estimates of the engineering properties (strength, elastic modules, permeability, and compressibility) needed for design in wetland soils.

Background

Wetland soils typically include hydric sediments with an organic component of decomposed plant material (peats and mucks). A hydric soil contains abundant moisture and in a wetland this soil will periodically be in a reduced state containing limited oxygen and a high water table. Sediments are materials that are deposited or settle to the soil surface from an overlying body of water. The organic material can influence soil parameters. Organic soils are readily identified by their color, odor, spongy feel and frequently by a fibrous texture.

The thrust of the engineering description should be to identify soil from the texture;i.e., relative size, shape, and hardness of soil particles. The soil description with some information on mass (density, void ratio, water content) properties is sufficient to estimate a typical range of in situ or compacted soil properties for ˋngineering applications.

Wetland soils are often sands with silts and clays with particle sizes typically less than 4.75 mm (No. 4 U.S. Sieve) as shown in Figure 1. Two soil classification systems, the Wentworth (Müller 1967) and the ASTM D 2487 (Unified Soil Classification System, USCS), are often used in the literature and a comparison of the two along with a visual and U.S. standard sieve reference is shown in Figure 1.

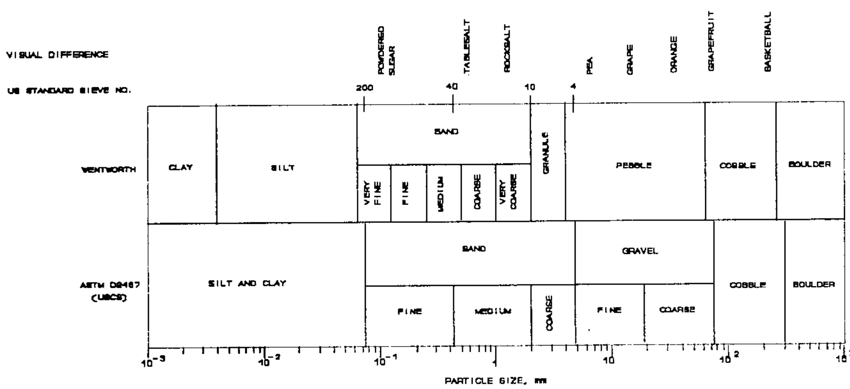

Figure 1. Particle Size Classification System

The ASTM D 2487/USCS (ASTM 1992) classification system, was originally designed for engineering design applications. This paper will reference this system for identities of soil in terms of group symbols and typical group names which can be obtained by expedient field and laboratory procedures. For example, a fined grained silt or clay may be described as an OL - organic silts and organic silty clays of low plasticity; slight to medium dry strength, slow dilatancy, slight toughness. Some soils found in wetlands described as soft, compressible, fine-grained soil such as organic silt (OL), organic clay (OH), normally consolidated plastic clay (CH), peat (PT) or muck are undesirable for supporting embankments, roads, structures or construction equipment. Sands (SC, SM-SC, SM, SP, SW), gravels (GW, GP, GM, GC) and certain lean clays (CL) usually provide the best soils for construction.

Engineering Description of Wetland soils

This paper provides guidance on how to describe wetland soils by field expedient and laboratory procedures. A field expedient description is useful to obtain a preliminary identification of soils and to determine preliminary engineering properties. The laboratory procedures accurately identify the soils and provided the best evaluation of engineering properties from soil description data.

Field Expedient Equipment. An approximate description of wetland soils may be made in the field by observation and tests with portable equipment to determine the parameters given below. Basic equipment required to complete a field expedient description of soils is given in Table 1. The equipment is geared to obtaining representative soil samples (near surface and at depth) and individual items could vary ,i.e., entrenching tools might be a shovel or a tractor backhoe. Obtaining representative soil samples requires consideration of the geomorphology of the area to avoid collecting too few or too many samples.

Table 1
Equipment for Field Expedient Soil Classification

Equipment	Remarks
> No. 40 U.S. standard sieve and, if available, No. 4 and No. 200 sieves	The breaking, dilatancy, dry strength, ribbon, roll, and toughness tests are performed on material passing the No 40. U.S. standard sieve. A No. 4 sieve is useful for separating gravel and a No. 200 sieve is useful for separating fines.
> Entrenching tools	Required for obtaining soil samples.
> Spoon	Mix water with cohesive soil to obtain a desired consistency.
> Pocket knife	Required for obtaining and trimming samples.
> Mixing bowl	Small container with a rubber-faced or wood pestle are required for pulverizing fine-grained portions of the soil.
> Heavy paper	Required for rolling samples.
> Pan and heating element	Required to dry samples for sieve analysis and to determine water content.
> Balances or scales	Required for weighing samples.

Field Expedient Tests. The **acid** test can determine the presence of calcium carbonate, a cementing agent, that can provide added soil strength to compacted soil over time. The test is conducted by placing a few drops of hydrochloric acid on a piece of the soil. A fizzing reaction (effervescence) indicates the presence of calcium carbonate.

The **bite** test is useful for identifying sand, silt, or clay. Sands grate harshly between the teeth, while silts feel gritty. Clays are not gritty, but feel smooth and powdery like flour.

A **break** test is an attempt to break a thoroughly dried soil pat by using the thumb and forefingers of both hands. A pat is a minus No. 40 sieve fraction molded to 13 mm (1/2 inch) thickness by 32 mm (1 1/4 inches) diameter in the wet plastic state and allowed to dry completely. Avoid breaks along shrinkage cracks because these will not indicate the true breaking strength. The soil is roughly described as follows:

CH - Soil cannot be broken or powdered or broken with great effort, but not powdered
CL - Soil can be broken and powdered with some effort
ML, MH, or CL - Soil easily broken and readily powdered
ML or MH - Soil crumbles and powdered when picked up in the hands

The **color** test distinguishes between different strata and assists the identification of the type of soil. Color classes are chroma (reds, greens, purples, browns, and pinks) and achroma (black, white, and grays). Both classes have brilliance, hue, and saturation attributes. Colors may be used to identify organic or inorganic soils, degree of saturation or drainage, and certain mineral contents. Wetland soils in a reduced state typically have a dark, gray, mottled appearance with 2 or less chroma colors.

The **dilatancy** test helps define the character of the fines in the soil. A pat of prepared moist soil is shaken vigorously. A positive reaction consists of the appearance of water on the surface of the pat which changes to a livery consistency and becomes glossy. When the sample is squeezed between the fingers, the water and gloss disappear from the surface, the pat stiffens, and finally it cracks or crumbles. Very fine clean sands give the quickest and most distinct reaction whereas a plastic clay has no reaction.

Geophysical tests or exploration by seismic, electrical, magnetic, and gravity methods is useful during the site evaluation to assist with identification of the soil profile and the location and thickness of the various strata.

Grain shape, determined by feel, influences soil stability. Irregular, angular particles cause interlocking between grains which increases frictional resistance and strength.

Odor, the sense of smell or fragrance, of a soil sample can indicate organic (OH, OL) soils which have a distinctive, musty, slightly offensive odor or hydric soils which have a rotten egg odor.

The **ribbon** test uses a pat of prepared soil (consistency of putty) is rolled to approximately 13 mm (1/2 inch) and then flattened with the fingers to approximately 6 mm (1/4 inch). The maximum length of ribbon that can be

supported by the cohesive properties of the soil without breaking indicates the cohesive properties of the soil.

The **roll** test consists simply of rolling a pat of prepared soil (consistency of putty) rapidly into a thread 3 mm (1/8 inch) in diameter. Materials which cannot be rolled into this thread at any water content are nonplastic or of low plasticity (ML or MH). If the soil can be rolled into a thread, then the degree of plasticity is determined as follows:

CH - Soil may be remolded into a ball and the ball deforms under extreme pressure by the fingers without cracking or crumbling.
CL - Soil may be remolded into a ball, but the ball will crack and easily crumble under finger pressure.
CL, ML, or MH - Soil cannot be lumped together into a ball without completely breaking up.
OL or OH - Soils containing organic materials or mica particles will form soft spongy threads or balls when remolded.

The **slaking** test is performed by drying shales or other soft rocklike materials, and then soaking them in water for at least 24 hours. Materials that slake appreciably are undesirable for construction.

The **toughness** test determines relative stiffness of a soil at the plastic limit water content. A pat of prepared soil (consistency of putty) is rolled into a thread about 3 mm (1/8 inch) diameter, then folded and rerolled repeatedly. The water content is gradually reduced and the specimen stiffens and crumbles when the plastic limit is reached. Generally, the tougher the thread becomes near the plastic limit is an indication of greater material strength while a weak and spongy thread is an indication of low strength or highly organic clays.

Laboratory Tests: USCS is a precise system for classifying mineral and organomineral soils for engineering purposes based on laboratory determination of Atterberg limits (liquid and plastic) and particle-size distribution. The ASTM version of the USCS is given as standard test method D 2487. Knowledge-based computer systems such as CLASS-92 (Bakeer 1992) expedite an efficient engineering description by the USCS. CLASS (Morse and Bakeer 1990) may be used to convert between Visual, USCS, ASTM, and AASHTO systems.

Atterberg limits are indices expressed in terms of the water content w of soil, in percent of the dry weight, that are useful for general characterization of soil, particularly to evaluate the degree of plasticity and compressibility:

a. **Liquid limit** LL, the upper percent - water content where the plastic state becomes a liquid. LL may be determined by ASTM D 4318.

b. **Plastic limit** PL, the upper percent - water content where the semisolid state becomes plastic. PL may be determined by ASTM D 4318.

c. **Plasticity index** PI, percent - difference in water content between the liquid limit and plastic limit, PI = LL - PL

Other identities, derived from the data obtained during the Atterburg limits tests, can be used to better define wetland or engineering soil properties.

Liquidity index, LI (percent), is the ratio of water content w minus PL to PI, or (w - PL)/PI.

Shrinkage limit, SL (percent) is the water content where the solid state becomes semisolid; least water content at which the degree of saturation is 100 percent.

Specific gravity of solids, G_s is the ratio of mass (grams or g) in air of a given volume of solids at a stated temperature to the mass in air of an equal volume of distilled water at the same temperature. Specific gravity, used to determine mass properties such as the density, void ratio, and degree of saturation may be applied to estimate engineering properties.

Particle size distribution determines the proportions (in percent) by mass of a soil or fragmented rock, similar to Figure 1, in specified diameter ranges of particle sizes; e.g., D_{10} is the particle diameter at which 10 percent of the material is finer by weight. Particle size distribution may be determined by standard test method ASTM D 422. Refer to ASTM D 2487 for other methods of gradation analysis. The following gradation ratios are also applied by the USCS to classify soil:

a. Coefficient of curvature Cc - $(D_{30})^2/(D_{10} \cdot D_{60})$.

b. Coefficient of uniformity Cu - D_{60}/D_{10}

Engineering Properties of Wetland Soils

It is beyond the scope of this paper to provide detailed discussion of engineering properties, therefore only brief definitions and guidance for evaluating the engineering properties of wetland soils required for wetland engineering are presented. Engineering properties evaluated from the engineering description of the wetland soils and its mass properties (density, void ratio, and water content) are strength, compressibility, and permeability. These engineering properties influence the critical soil processes that govern the performance of a wetland when a force is applied to the soil. Critical soil processes include the compaction characteristics of fill materials used to construct dikes, slope stability and settlement of earth dikes retaining water and soils in wetlands, compaction characteristics of wetland soils, sedimentation and erosion characteristics of wetland soils, and the flow of water through wetlands and dikes. These processes influence water and sediment storage capacity, water quality and flow, and erosion from and collection of sediments on the surface of submerged wetland soils. The strategy for determining procedures for

construction or restoration, operation, and maintenance of wetlands is based on the critical soil processes evaluated from the engineering properties of wetland soils.

Information required to determine engineering properties for final design, restoration, construction, and maintenance of wetlands may be provided from results of detailed site evaluation and soil survey. The survey should include in situ soil tests such as cone penetration (CPT) and standard penetration (SPT) and laboratory tests performed on undisturbed soil samples. Hand-operated piston, Shelby push tubes, rotary, and samplers are available for retrieving disturbed and undisturbed soil samples (EM 1110-2-1907).

Mass Properties

As stated mass properties are the density, void ratio, and water content of the soil and brief definitions of these and other definable properties are stated below. Field expedient procedures to collect data, when available, are mentioned.

Density, g/cc is mass per unit volume of material:

a. Wet density γ - in-place total mass per unit total volume of material. γ may be determined by ASTM D1556, D2167, or portable field methods given in Appendix E of EM 1110-2-1907.

b. Dry density γ_d - mass of solid particles per total volume of material. γ_d may be determined from $\gamma/(1 + w/100)$ where w is the water content on a dry weight basis in percent.

c. Saturation density γ_{sat} - wet density at which the pore water pressure of a normally consolidated undisturbed soil is zero.

Desiccation limit $_{DL}$ is the least void ratio of soil caused by desiccation. $e_{DL} \approx 1.6 + 0.0106PI$ and it occurs approximately at a degree of saturation of 60 percent.

Liquidity index LI (percent) is the ratio of water content w minus PL to the PI, (w - PL)/PI. LI close to and exceeding unity indicate normally consolidated soils, recently deposited sediments, and a potential of being wetland soils. LI exceeding unity indicates soil on the verge of being a viscous liquid. LI close to or less than zero indicates overconsolidated, desiccated soil and soil with high foundation strength.

Void Ratio, e, is the ratio of the volume of void space to the volume of solid particles in a given soil mass. $e = (G_s/\gamma_d)\gamma_w - 1.0$ where G_s = specific gravity, γ_d = dry density, g/cc, and γ_w= unit mass of water, 1 g/cc.

Water content w, (percent) is the ratio of the mass of water contained in the pore spaces of soil to the mass of solid dry material expressed as a percentage. Soil water content may be evaluated in the laboratory by ASTM D2216 or microwave oven method D4643. The natural water content of in situ soil can indicate drainage characteristics and nearness to a water table. The optimum water content of compacted fill materials allows compaction to the greatest density and strength. Two field expedient test methods are:

a. Natural water content test. A piece of undisturbed soil is tested by squeezing it between the thumb and forefinger to determine its consistency; i.e., hard, stiff, brittle, friable, sticky, plastic or soft. The soil is them remolded by working it in the hands, and changes, if any, are observed. Clays which turn almost liquid on remolding are probably near or above the liquid limit. If the clay remains stiff and crumbles upon being remolded, the natural water content is below the plastic limit.

b. Optimum water content (OMC) test. A golf ball size of soil is molded by hand and squeezed between the thumb and forefinger. If the ball shatters into several fragments of rather uniform size, the soil is near or at OMC. If the ball flattens out without breaking, the soil is wet of the OMC. If the soil is difficult to roll into a ball or crumbles under very little pressure, the soil is dry of the OMC.

Identification and Evaluation of Engineering Properties

Engineering properties are the strength, compressibility, and permeability parameters of the soil. Under this subheading there is a synopsis of the definitions and the evaluation techniques.

Strength properties or parameters define the ability of soil to support dikes, retaining walls, pavements, and other structures and to resist erosion from flowing water. The shear strength τ is given by Coulomb's equation in terms of strength parameters c (cohesion) and ϕ (angle of internal friction), $\tau = c + \sigma_n \tan\phi$.

Cohesion, c, kPa is the shear resistance at zero normal stress or the intrinsic shear strength. A perfectly cohesive soil has strength only from cohesion where $\phi = 0$. The shear strength of a clay when undrained is $c = C_u$ where C_u is the **undrained shear strength**. The **compressive strength** q_u is twice the undrained shear strength. q_u is usually determined on specimens not confined by any applied stress.

Unconfined compressive strength q_u, kPa can be estimated using a pocket penetrometer. The small, hand-operated, spring-calibrated penetrometer for estimating the engineering consistency of cohesive, fine-grained soils, table 2. The device is pushed into soil surfaces as described by Bradford (1986). Clays of medium or softer consistency are normally consolidated and may be

in wetlands. Stiff and harder clays are overconsolidated. Two methods to estimate strength:

a. Vane torque T_v, N·m. The turning moment required to shear a cylindrical column of cohesive soil. The torque may be determined by a four-bladed vane device according to standard test method ASTM D 2573.

b. Undrained shear strength C_u, kPa. The maximum resistance to shear forces when pore pressures are not drained. C_u is required to evaluate slope stability and bearing capacity of cohesive soils. C_u may be estimated from results of the pocket penetrometer test as 1/2 of q_u, the unconfined compressive strength. C_u may also be estimated from results of the field vane shear test by T_v/K_v where K_v is the vane constant.

Angle of internal friction ϕ, deg is the angle between the normal stress axis and tangent to the Mohr envelope at a point representing a given failure stress of the soil. ϕ is required to evaluate the slope stability and bearing capacity of cohesionless soil or sands. ϕ is usually estimated from correlations of field soil tests such as cone penetration (CPT) or standard penetration (SPT) tests because undisturbed boring samples for laboratory tests are rarely obtainable for sands. Table 3-1 in EM 1110-1-1903 provides correlations of ϕ with relative density, CPT, and SPT. Figure 2 correlates the soil classification and the dry unit weight γ_d with ϕ when CPT or SPT data are not available.

Table 2
Correlation of Consistency With Shear Strength of Cohesive Soil

Relative Consistency	Unconfined Compressive Strength Q_u, kPa
Fluid mud	< 2
Very soft	2 - 25
Soft	25 - 50
Medium	50 - 100
Stiff	100 - 200
Very stiff	200 - 400
Hard	> 400

Compressibility properties include both elastic and consolidation parameters. Elastic parameters define the ability of soil to resist elastic deformation and settlement from applied forces. Elastic deformation occurs almost immediately and accounts for nearly all or most of the settlement in cohesionless soil. Consolidation parameters define the ability of saturated soil to resist

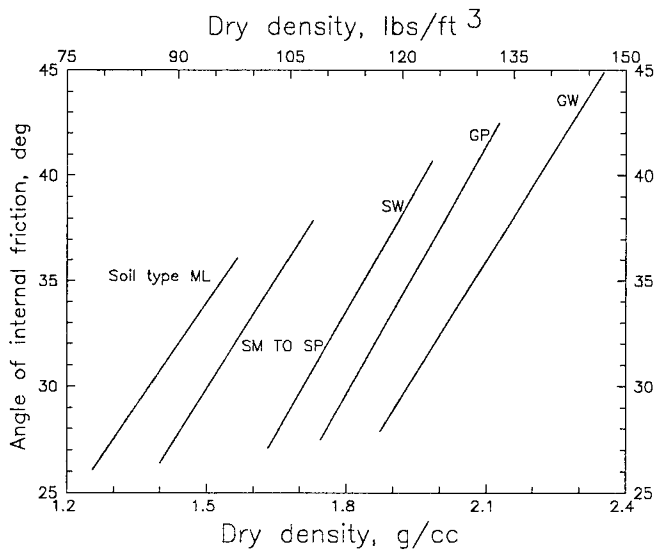

Figure 2. Strength characteristics for cohesionless soils

settlement or heave caused by applied forces. Changes in applied forces and the resulting consolidation due to the outward flow of water (permeability properties) occurs over a relatively long time and often accounts for most of the settlement in a cohesive soil. Determination of these properties requires laboratory testing of representative soil samples which yields data required to calculate needed design values: modules of elasticity, shear modules, compression index, recompression index, and overconsolidation ratio. These design values will not be discussed in this paper.

Permeability is a property of a soil mass that defines the rate of flow of water Q through the soil. Permeability is influenced by the void ratio, continuity of voids, and fissures that may be caused by drying and wetting weather cycles. Permeability is defined as the flow of water Q through a cross-section area A of soil depending on the hydraulic gradient i, $k = Q/(iA)$. Permeability affects the rate of consolidation or volume change of a soil which in turn affects dike heights, construction sequence, and future permeabilities of the entire wetland. Information is available to correlate permeability from other properties easier to obtain as shown in Figure 3 and Table 3.

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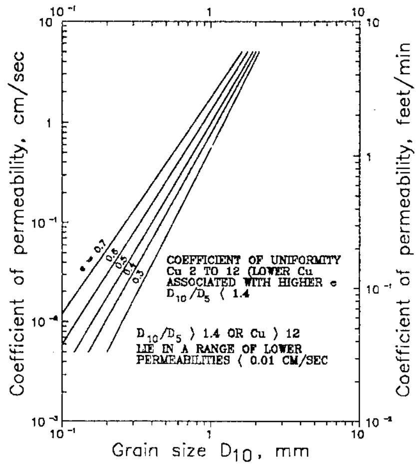

Figure 3. Permeability of sands and sand-gravel mixtures from void ratio and gradation data (After NAVFAC DM-7.1). e - void ratio; Cu = coefficient of uniformity, D_{60}/D_{10}

Table 3
Coefficient of Permeability by Soil Classification

Soil Type	k, cm/sec
GW-SW	$> 20^{-2}$
GP-SP	$5 \cdot 10^{-4} - 10^{-2}$
MP-OL	$10^{-5} - 5 \cdot 10^{-4}$
GF-SF-MH	$5 \cdot 10^{-7} - 5 \cdot 10^{-4}$
GC-SC-CL	$5 \cdot 10^{-7} - 10^{-5}$
CL-CH-OH	$< 5 \cdot 10^{-7}$

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Sediment Diversion Projects, Plaquemines Parish, Louisiana, R. Steve Fox Corps of Engineers, New Orleans, Louisiana New Orleans, Louisiana

Abstract

Excavation of a sediment diversion channel through the bank at Baptiste Collette Bayou and South Pass, Mississippi River delta, Louisiana, would result in the development of small-scale delta splays. Water and sediments would be diverted through the banks into shallow estuarine open water resulting in the creation of about 26 hectares (65 acres) of fresh to intermediate marsh over a period of 20 years.

Introduction

The U.S. Army Corps of Engineers, New Orleans District, recommended construction of a sediment diversion channel (channel) at Baptiste Collette Bayou and South Pass located in the Mississippi River delta in Louisiana to divert water and sediments. These channels will result in the development of delta splays and marsh vegetation. Sediment diversions imitate the formation of natural delta-splays and marsh as described by the U.S. Army Corps of Engineers in 1985 (Corps 1985).

Water and sediments diverted through the channels into the adjacent shallow estuarine open water will result in the creation of fresh to intermediate marsh vegetation. Depths of the shallow estuarine open water areas are less than 1 m (3 ft). Fresh (0-1 part per thousand) to intermediate (1-6 ppt) marshes have average elevations of + 1.9 ft MLG.

One channel will be through the south bank of Baptiste Collette Bayou (Figure 1), and one will be through the west bank of South Pass (Figure 2). The marshes along Baptiste Collette Bayou are fresher than those of South Pass.

The operational life of each channel is expected to be five years. The fresh to intermediate marsh created is expected to persist for over 20 years.

Materials and methods

Construction will consist of excavation of a channel through the bank at each pass (Figure 3). The length of the channel through the bank at Baptiste Collette Bayou will be 122 meters (400 feet), the width would be 30 m (100 ft), and the depth will vary uniformly from - 2.4 m (8 ft) N.G.V.D. at the confluence of the channel and Baptiste Collette Bayou to the elevation of the

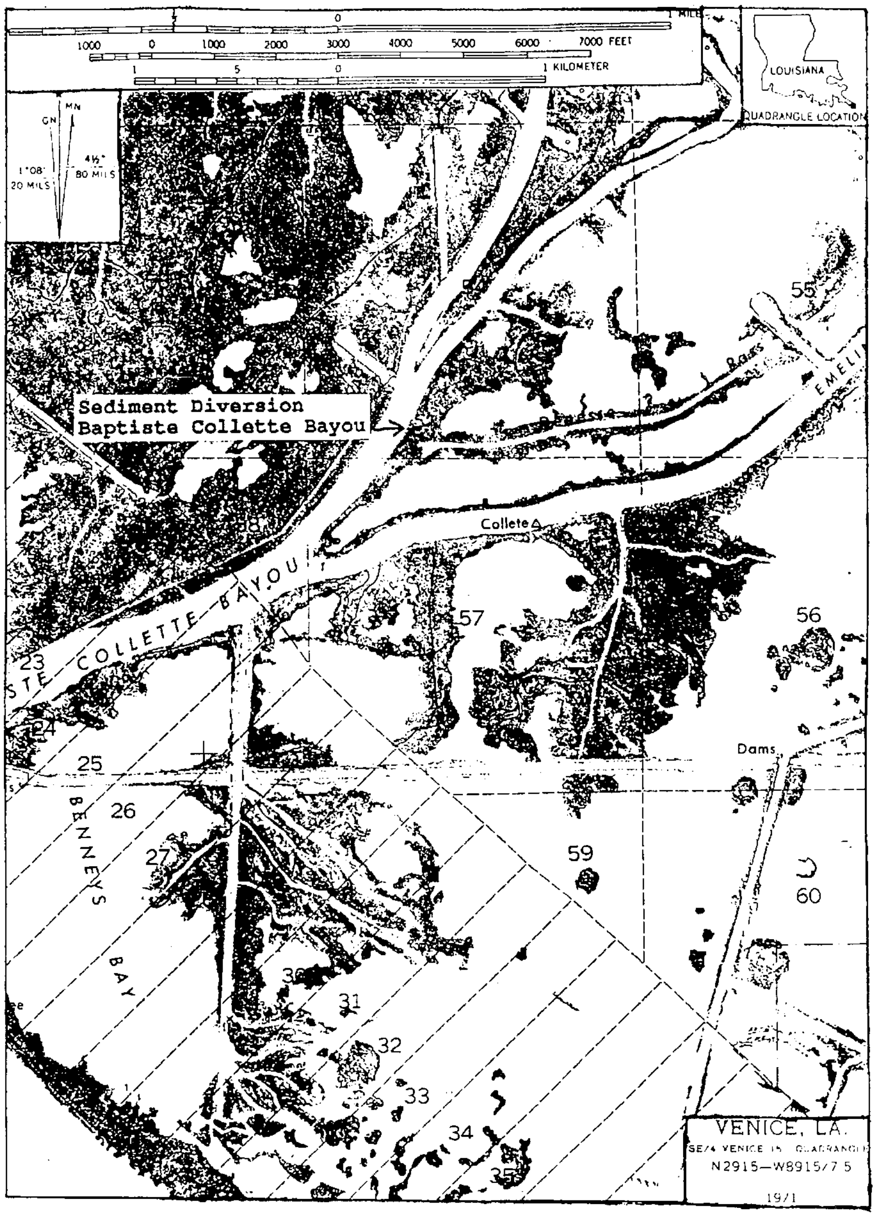

Figure 1. Baptiste Collette Bayou Sediment Diversion, LA

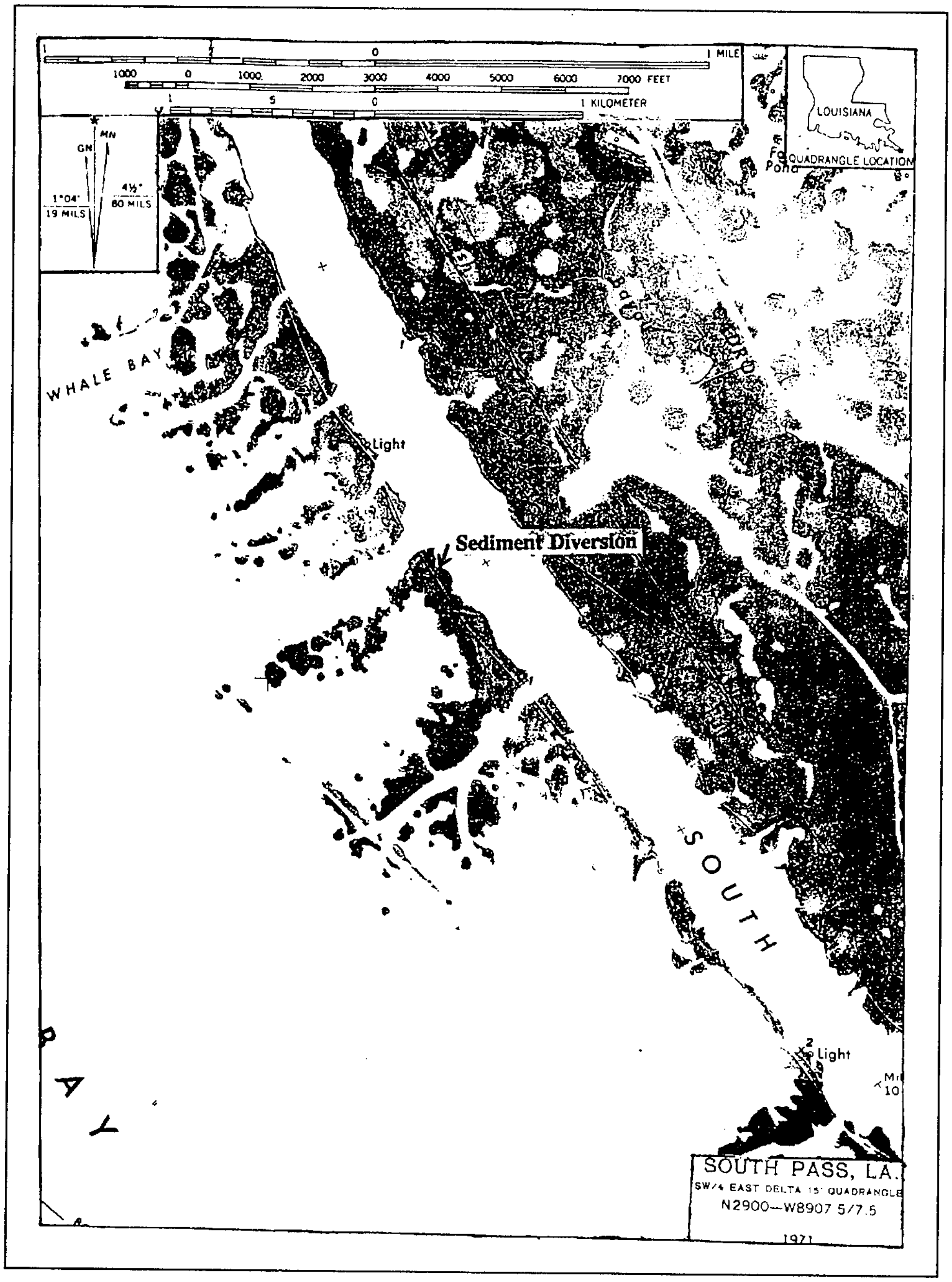

Figure 2. South Pass Sediment Diversion, LA

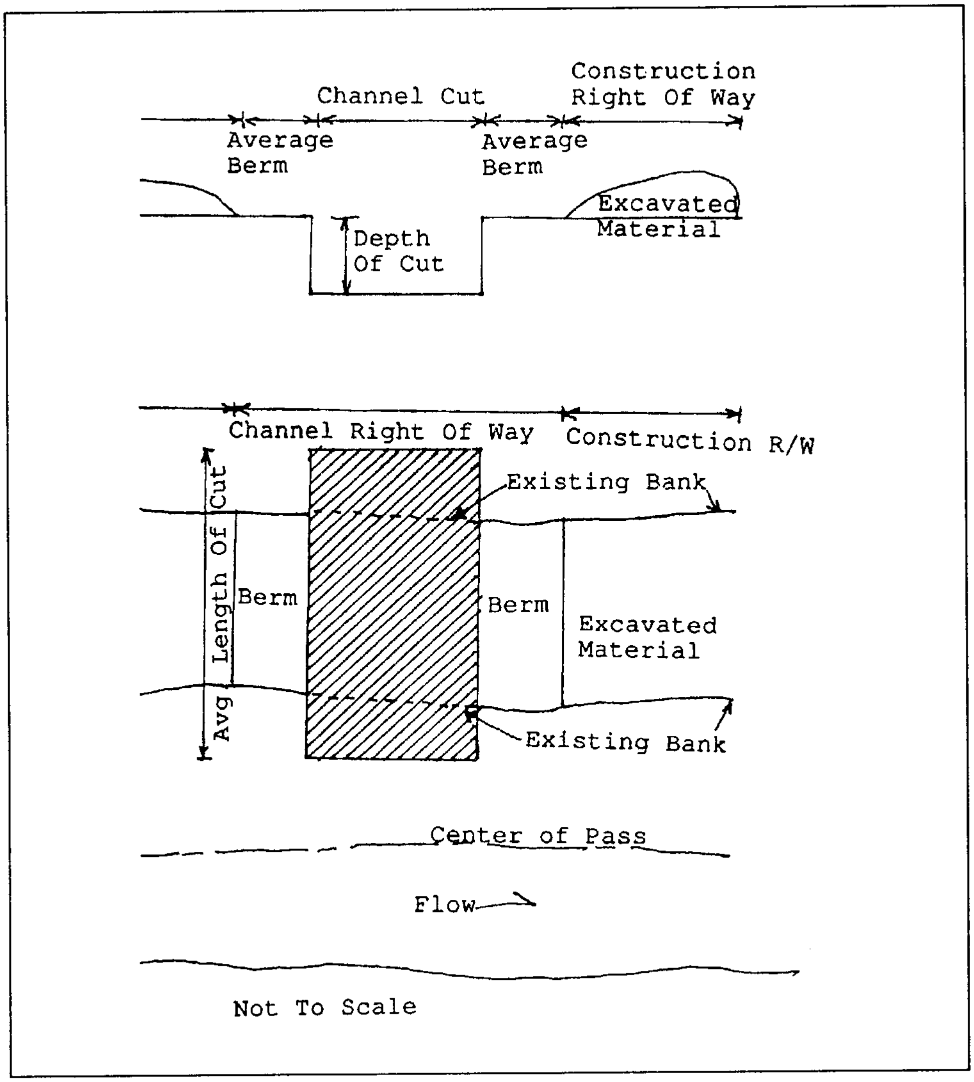

Figure 3. Typical Sediment Diversion

target marsh area (Table 1). The average annual flow diverted through the channel at Baptiste Collette Bayou will be 2,025 cubic feet per second (cfs). The length of the channel at South Pass will be 415 m (1360 ft), the width would be 38 m (125 ft), and the depth will vary uniformly from - 2.4 m (- 8 feet) N.G.V.D. at the confluence of the channel and South Pass to the elevation of the target marsh area. The average flow diverted through the channel at South Pass will be 1,265 cfs.

Results and discussion

A delta-splay of fresh to intermediate marsh will establish along Baptiste Collette Bayou and will total about 4 hectares (10 acres) per year for five

Table 1
Sediment Diversions, Baptiste Collette Bayou and South Pass, Plaquemines Parish, LA

Sediment Division Channel	Sediment Diversions				Marsh Created (ha) Year		
	Length (m)	Width (m)	Depth (N.G.V.D) (m)	Flow (cfs)	1	5	20
Baptiste Collette Bayou	122	30	-2.4 to + 0.6	2,025	4	16	14
South Pass	415	38	-2.4 to + 0.6	1,265	2.6	13	12
Total	-	-	-	-	6.6	29	26

years. Approximately 14 ha (35 ac) of the established marsh at Baptiste Collette Bayou will remain after 20 years. A delta-splay of fresh to intermediate marsh will establish along South Pass and will total about 2.6 ha (6.5 ac) per year for five years. Approximately 12 ha (30 ac) of the established marsh at South Pass will remain after 20 years. These small-scale, uncontrolled, sediment diversions will allow delta-splays to develop, creating approximately 33.6 ha (83 ac) of marsh in adjacent shallow estuarine open water areas during an expected five-year operational period. A total of approximately 26 ha (65 ac) of the created marsh will be expected to persist for over 20 years.

Summary and conclusion

Because these diversions are expected to create about 26 ha (65 ac) of marsh benefitting the natural resources of the area, these projects should be implemented rapidly.

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Low-Impact Restoration of a Forested Wetland, Upland, and Stream Corridor in Southern Maine, David P. Cowan, Senior Scientist, Normandeau Associates, Inc., Yarmouth, Maine

Introduction

The Maine Department of Transportation (MeDOT) is completing construction of a major reforestation and erosion control project as partial compensation for wetland impacts resulting from construction of a new interchange on the Maine Turnpike in the Town of Scarborough. The project, designed and overseen by Normandeau Associates, Inc. (NAI) of Yarmouth, involves reforestation of an 18-acre site that had been severely degraded by removal of vegetation and topsoil, filling of floodplain wetlands, and exposure of unstable subsoil to erosive forces. Existing site conditions and design objectives led to the use of innovative and non-traditional approaches to achieve site restoration goals. This paper provides an overview of the project and the existing conditions and constraints encountered, and chronicles our experiences to date with the techniques employed.

Sight Overview

The Mill Brook Reforestation Site is located within a mile of the seacoast in southwestern Maine. The site is bisected by a 2,000± foot section of Mill Brook, a second-order stream that flows through mixed suburban development before discharging into the Scarborough Marsh Wildlife Management Area, a vast salt marsh complex situated about 1.3 miles downstream of the project site. Land uses immediately surrounding the site include moderate-density residential and light commercial development, and on two sides, sizable tracts of undeveloped forest. Topography of the site and the surrounding area is generally flat to gently rolling. Predominant soils of the region are derived from fine-textured marine and lacustrine sediments, overlain in many areas by coarser-textured soils of glaciofluvial origin. Depth to bedrock is generally five feet or more.

Although limited clearing and grubbing was evident in 1983 aerial photography of the site, major stripping and regrading occurred primarily during the 1985-87 period. By 1988 approximately 40 acres of former forest, including the Mill Brook stream corridor and an unknown quantity of wetland, had been stripped. The 18-acre parcel acquired by MeDOT to fulfill its mitigation obligations included the degraded section of Mill Brook, 6± acres of floodplain wetlands, and a riparian buffer consisting of 12± acres of upland and 2± acres of wetland.

In addition to deforestation, baseline studies for site restoration documented severe erosion, buried waste and fill material, and water quality degradation in Mill Brook.

An additional factor identified during baseline studies was the popularity of the site as a local recreation area both prior to and following disturbance.

Restoration Objectives

From a regulatory standpoint, the objective of the Mill Brook Reforestation site is to offset impacts to forested wetlands from new highway construction. Wildlife habitat impacts resulting from the fragmentation of existing forest blocks in the project vicinity was of particular concern. Thus part of the rationale for selecting the Mill Brook site, in addition to the obvious benefits to the riparian corridor and adjacent wetlands, was to expand the perimeter of the contiguous forest block abutting the property on two sides.

To achieve this overall objective, NAI's restoration plan was developed with three secondary objectives in mind:

a. Arrest on-going soil erosion and stream sedimentation and provide immediate stabilization of erosion-prone areas.

b. Restore and improve soils and establish forest vegetation, taking into account the variability of existing soils and vegetation across the site, as well as the variety of habitats such as stream, floodplain wetland, embankment slopes, and wetland and upland terraces.

c. Provide both short- and long-term access to the site for construction and maintenance, respectively, without compromising the overall objective of establishing a contiguous forest community. Consider also the affects of continued public use of the site and methods of limiting or controlling public access.

Non-Traditional and Innovative Approaches

To meet these objectives, a number of non-traditional and innovative approaches were employed with varying degrees of success ranging from moderate to high. These techniques, their rationale, and their performance to date are summarized below:

Erosion control

Plant Carpets. Areas of concentrated runoff such as swale channels were treated using coir fiber carpets pre-planted with a mixture of wetland sedges and rushes. The plant carpets used were approximately 2 inches thick with an interior of 100% coir fiber felt and an exterior of woven 100% coir fiber fabric. Plugs of mature plants were rooted into the carpets at a spacing of 2-feet on center prior to installation.

Swale Treatments. Gullies with unvegetated, steep sides were graded to form broad swales that were then treated with a combination of woodwaste mulch/loam mix, jute mesh, and plant carpets. A typical graded swale was topdressed with four inches of woodwaste mulch/loam mix. Jute mesh covered the entire width of the swale, with a three foot wide plant carpet counter-sunk along the length of the flow line.

Rototilled Rows. Planting of tree and shrub seedlings on slopes adjacent to the floodplain was accomplished using planting rows that were rototilled parallel to the slope contours. This method achieved three objectives. First, existing herbaceous growth in the rows was set back to reduce light and water competition for the new seedlings. Second, most of the existing growth on the slopes remained intact thus minimizing disturbance that could lead to erosion. Finally, the method allowed for mechanized, large scale preparation of planting beds including incorporation of soil treatments into the upper soil profile.

Soil treatments

Woodwaste Mulch. This is a composed by-product of the timber industry's log-handling operations. Woodwaste mulch is available in a medium texture, suitable as a soil amendment, and in a coarse texture specifically marketed as a topdress for erosion control. Both are derived from flume grit and yard waste, and are composed of bark and wood fragments, sawdust, sand, and gravel. The material is aged and is high in organic matter (25 - 35%), low in nutrients, with an average pH of about 6.0.

Three parts medium-textured woodwaste mulch was added to one part topsoil salvaged from the highway construction site. This woodwaste mulch/loam mix was used in topsoil applications throughout the site.

Municipal Compost. Also used as a soil amendment, this material is derived from dried municipal sewage sludge. Uniformly fine in texture, it is high in organic matter (30%) with a pH of 7-8, and a low nutrient value. Municipal compost was mixed at a rate of one part to three parts salvaged topsoil and used in topsoil applications.

Soil Mixtures. The applications of mixtures of salvaged topsoil, woodwaste mulch and municipal compost were designed based on the specific needs and constraints in each part of the site (Table 1). As a rule, use of municipal compost was limited to areas where there was low potential for the finer material to be carried into the stream by runoff.

Aerospreader/Forwarder. An aero-spreader mounted on a 6-wheel drive articulated forwarder was used to apply topdress material onto areas where existing vegetation and/or slopes made use of a bulldozer undesirable. The aero-spreader broadcasts material up to 2" in diameter for a distance of 100 - 150 feet. The aero-spreader was able to apply the specified topdress in a

Table 1
Existing Conditions

Soil Quality	Vegetation Cover	Potential Run-off to Stream	Proposed Treatment
Poor	Little or more	Low	4" loam/compost mix incorporated by rototilling
Moderate	Moderate - High	Low	2" loam/compost mix topdress by aero-spreader
Moderate	Moderate - High	High	2" woodwaste mulch/loam mix topdress by aero-spreader
Poor	Moderate	High	4" woodwaste mulch/loam mix topdress by aero-spreader
Poor	Little or none	High	4" woodwaste mulch/loam mix Incorporated by rototilling

nearly uniform layer that conformed to the existing topography while minimizing damage to existing vegetation. In areas where access was limited, the forwarder was unimpeded by obstacles such as grubbings and uneven terrain.

Access

Access throughout the site was deemed essential for both construction and long-term maintenance of the site. An additional consideration was public use, which was accepted as inevitable given the site's location, large perimeter, and tradition of use. Measures to address these issues are summarized below.

Roads. A network of gravel roads was constructed to allow heavy equipment access to the site during all stages of construction as well as for longterm maintenance. In addition, the washed-out stream crossing was re-constructed to allow temporary access across Mill Brook. Following construction all gravel roads were topdressed with 2-4" of woodwaste mulch/loam mix and seeded, and the temporary stream crossing was removed and the stream and floodplain restored. The access network provides a framework for controlled public use of the site, directing foot traffic to established trails and away from planted areas.

Permanent Stream Crossing. To facilitate long-term maintenance access to the entire site, a permanent ford was constructed across the stream at a new location. The new location was selected where streamflow is typically less than 6-inches deep over a bed of smooth ledge. Approaches to the ford across the floodplain of the stream were constructed of rip-rap, counter sunk to match the existing grade.

Log Barriers. Selectively placed log barriers were used in conjunction with the access road network to direct public use of the site away from

sensitive areas. The logs themselves were salvaged from clearing of the highway construction site. NAI's project forester worked with the contractor to select the lowest value trees that would meet design specifications. Nearly all of the trees used were red spruce (*Picea rubens*) and balsam fir (*Abies balsamea*) trunks, approximately 30-feet in length, with stubs of branches left intact to help anchor the barriers in place. Logs were placed end-to-end to form barriers that ran perpendicular to access trails. Additional barriers were placed to block key points of traditional access and direct traffic to newly established trails.

Evaluation to date

Soil Amendments. Woodwaste mulch and municipal compost both performed well in handling and, so far, have not proven troublesome after installation. Their benefits in terms of improving soil quality on the site have yet to be assessed. If they perform as intended, they show good promise as a soil amendment and, because they are recycled products, are consistent with a soil conservation ethic.

Plant Carpets. Plant carpets installed on the Mill Brook site provided immediate and effective erosion control from the time they were installed in October 1992. Because they were planted only with vegetation plugs, however, their functioning was primarily a result of the fiber carpet itself. Spring seeding of the swales has subsequently outpaced the spread of the plant plugs in most areas.

Swale Treatments. The specified swale treatments have effectively arrested excessive erosion on the site. The swales are stable and have since been planted with native bare root and cutting stock.

Rototilled Rows. Rototilling was most effective for bed preparation under relatively dry soil conditions. Suboptimal conditions proved deceptively hard to judge, especially in areas where the silty-clay subsoil was near the surface. Nonetheless, the majority of the work was completed as scheduled. The goal of maintaining stable slopes with existing vegetation was likewise achieved. The value of rototilling for suppressing herbaceous competition has yet to be fully evaluated.

Aerospreder/Forwarder. This highly specialized equipment combination, most commonly used for forest applications of sludge, proved an efficient alternative to traditional soil spreading methods such as bulldozers. The aerospreader was surprisingly fast at topdressing large areas, rivalling the bulldozer in applications up to 4" deep. The advantages of minimal traffic plus uniformity of spread were highly desirable. The single biggest problem proved to be particle size. Stones and organic debris over 2"-diameter inevitably clogged the impeller mechanism, requiring time-costly maintenance. Thorough screening and contamination prevention of the topsoil mixture is recommended.

Access Roads. Construction of access roads in the fall of 1992 required substantially more gravel than originally anticipated to support heavy equipment on the site. Waiting for a drier season would have reduced the gravel cost, but would have interfered with the spring planting schedule which depended on the completion of earthwork and soil treatments.

Stream Crossing. Construction of the permanent ford over ledge was completed this summer and it appears to be stable and functioning as designed.

Log Barriers. At a total cost of about $6,000, the 3,000 feet of log barriers has so far been a cost-effective approach to limiting public access. Moreover, they are easily augmented or relocated in response to changing conditions.

Soils and Site Selection in Wetland Construction, Mallory N. Gilbert, B.S., M.S., CPSS, CPESC, M.N. Gilbert Environmental Consulting and Planning Services, State College, Pennsylvania

Abstract

Soils that become part of a constructed wetland substrate and/or subgrade are acknowledged as potential points of significant water loss from the wetland system. Consequently, soil physical properties such as texture, structure, depth to lithic or paralithic contact, depth to seasonal or regional watertables, horizon permeabilities, and horizon hydraulic conductivities are elements that must be documented in order to predict water losses through the soils of constructed wetlands. Soil profile morphology is helpful in predicting depth to seasonal watertables, but such predictions must be tempered with an understanding of how redoximorphic features can be formed within the soil-water capillary fringe. Designers are cautioned not to use the depth to first mottling in a soil profile as a reliable indicator of watertable depth throughout the growing season. Watertable data collected from open test pits and/or monitoring wells observed through two or more winter/spring cycles are suggested to support more accurately the prediction of seasonal watertable elevations. Even substantial water losses through the soil substrate can be balanced by a surplus supply of surface water. In cases where surface water alone is insufficient to sustain wetlands hydrology, water supplies may be increased by excavating deep enough to exploit seasonal or regional watertables. Where surface and subsurface water supplies are limiting or marginal, soil subgrade compaction, use of compacted clay liners, or use of synthetic liners (when approved by reviewing regulatory agencies) may help to offset potential water losses through the wetland substrate. Use of a clay liner compacted to 95% of its maximum dry density has yielded a permeability coefficient of approximately 2.2×10^{-6} cm/sec when installed over a highly permeable fractured (ripable) shale subgrade. This clay liner has been shown to be an effective means of ensuring adequate hydrology in a constructed wetland near Harrisburg, Pennsylvania. Data obtained from thorough soils investigations conducted in and around proposed wetland construction sites can provide advanced knowledge of potential soil/water problems. When included as part of a site's potential water budget, soils information can be critical to the success of a wetland creation project.

Introduction

An integral part of all earth moving civil engineering applications should be a basic knowledge of the soils in which one is working, especially if the soils will become a critical structural component of the planned project. This principle is particularly important when planning and constructing ponds, dikes, levees, roads, all manner of foundations, and, of course, artificially created wetlands. Even the most intricate planting plan (vegetation) coupled

with a generous volume of ground water and/or surface runoff water (hydrology) cannot always be expected to overcome a previous substrate (soils) problem. Soils must be considered early in the wetlands construction planning process and must be recognized as a critical component of the wetland water budget. The soil substrate can be manipulated to form a vessel in which wetland hydrology is held, or, it can function a pervious medium that allows ground water to move into and throughout the wetland system. Following final grading, soil must also act as a medium for plant growth.

In addition to evapotranspiration and flow-through (water that leaves the system as excess volume and flows through and then out of the wetland), water loss though the soil substrate is one of the three primary water "exports" from natural and artificially created wetland systems. Measurement of soil hydraulic conductivity and/or permeability coefficient (percolation rate) can be helpful in predicting water losses through the substrate of a constructed wetland system. In many naturally occurring wetland systems, permeabilities of hydric soil horizons are frequently greater than might be expected; and, in the case of many alluvial soils, permeability may actually increase with depth (Table 1).

Due to seasonal and/or regional watertable influences, the soil substrate remains saturated for a significant portion of the growing season in many natural wetland systems. In these wetland systems a higher rate of permeability in the saturated portion of the soil profile is not a concern, and ground water becomes a very important water budget "import". However, when considering an upland area as a potential site for a constructed wetland, even moderate to slow rates of permeability in one or more soil horizons may be considered excessive when the sources of hydrology are limiting or unproven (i.e. questionable depth to seasonal or regional ground watertable and/or a relatively small watershed).

Soil horizons in some natural wetland systems have potential to infiltrate water at rates in excess of 120 centimeters per day. With high rates of water infiltration, how is it that these wetlands remain wet enough, long enough "to support a predominance of hydrophytic vegetation"? The answer often lies in the landscape position of the natural wetland relative to adjoining uplands and the water sources providing the wetland hydrology. The majority of natural wetland systems occupy low landscape positions or depressional areas where surface runoff concentrates and/or lateral subsurface flows discharge or rise to within a few inches of the soil surface (sidehill seeps/springs are obvious exceptions). Many of these systems have surplus hydrology in the form of surface runoff water, perennial streams, and/or ground water discharge. Where there is a surplus water supply, the importance of soil permeability is often minimized. Many unique and highly productive ecosystems are associated with wetlands that have surplus hydrology during part or all of the growing season.

Table 1
Depth to Anticipated High Water Table and Range of Anticipated Soil Permeabilities at Varying Depths for Selected Soils[1]

Soils Series/Depth	Anticipated Permeability Range	Depth to Anticipated High Watertable
Atkins (silt loam) (Typic Fluvaquents[2]) 0 - 20 cm 20 - 127 cm 127 - 152 cm	 $65.6 - 218.7 \times 10^{-6}$ cm/sec $6.6 - 218.7 \times 10^{-6}$ cm/sec $21.9 - 656.1 \times 10^{-6}$ cm/sec	0 - 30 cm (apparent) (Nov - Jun)
Pope (loam) (Fluventic Dystrochrepts[2]) 0 - 15 cm 15 - 102 cm 102 - 152 cm	 $65.6 - 218.7 \times 10^{-6}$ cm/sec $65.6 - 656.1 \times 10^{-6}$ cm/sec $65.6 - 656.1 \times 10^{-6}$ cm/sec	>183 cm
Purdy (silt loam) (Typic Ochraquults[2]) 0 - 15 cm 15 - 102 cm 112 - 152 cm	 $65.6 - 218.7 \times 10^{-6}$ cm/sec $<21.9 \times 10^{-6}$ cm/sec $<21.9 \times 10^{-6}$ cm/sec	0 - 30 cm (apparent) (Nov - Jun)
Sloan (silt loam) (Fluvaquentic Haplaquolls[2]) 0 - 30 cm 30 - 114 cm 114 - 152 cm	 $65.6 - 218.7 \times 10^{-6}$ cm/sec $21.9 - 218.7 \times 10^{-6}$ cm/sec $21.9 - 218.7 \times 10^{-6}$ cm/sec	0 - 30 cm (apparent) (Nov - Jun)
Brinkerton (silt loam) (Typic Fragiaqualfs[3]) 0 - 53 cm 53 - 102 cm 102 - 152 cm	 $65.6 - 218.7 \times 10^{-6}$ cm/sec $6.6 - 21.9 \times 10^{-6}$ cm/sec $6.6 - 65.6 \times 10^{-6}$ cm/sec	0 - 15 cm (perched) (Sep - Jun)
Buchana (silt loam) (Aquic Fragiudults[3]) 0 - 53 cm 53 - 152 cm	 $65.6 - 218.7 \times 10^{-6}$ cm/sec $6.6 - 21.9 \times 10^{-6}$ cm/sec	30 - 60 cm (perched) (Nov - Mar)

[1] Data provided in this table were taken from various Ohio and Pennsylvania county soil surveys published by the National Cooperative Soil Survey through the USDA Soil Conservation Service. Permeabilities listed in these publications are presented in inches per hour and are estimated based on soil structure and texture. Although these data are valuable in helping a wetland designer to select a potential site, additional field tests are encouraged to verify the site conditions.
[2] Soils formed in alluvium and usually found in floodplains. Atkins, Purdy, and Sloan series are listed as hydric soils.
[3] Soils formed in colluvium and usually found in upland landscape positions. The Brinkerton series is listed as a hydric soil.

Nontidal wetland hydrology is generated and maintained in a number of ways. Some typical sources of freshwater wetland hydrology are listed below.

a. A seasonally high watertable that rises within the soil profile during the winter and remains through early spring (often noted in alluvial soils of floodplains adjacent to creeks, streams, and rivers or in

lacustrine soils influenced by nearby ponds, lakes, and reservoirs).

b. A perched watertable held near or above the soil surface by a slowly or very slowly permeable layer within the soil profile (perched water from direct precipitation, runoff, and/or infiltration and lateral movement from adjacent upland areas). A perched watertable usually is isolated from or only weakly associated with the regional watertable. Soils with fragipans and soils formed in or on dense glacial tills frequently have perched watertables. A perched watertable may also occur as a result of a finer textured soil horizon that is positioned above a more porous and coarser textured horizon. This type of "perched" watertable where water resists draining and is held by capillary forces, is a well documented phenomenon associated with stratified soils.Contact with a relatively stable regional watertable.

c. Contact with a relatively stable regional watertable.

d. Frequent flooding/ponding from nearby streams, rivers, or other bodies of water.

e. A surplus and/or steady supply of surface water runoff (sufficient drainage area/watershed), spring water, and/or groundwater that is discharged directly into the wetland or the surface water conveyances (brooks, streams, drainage ditches, etc.) that feed the wetland system.

Depending on the nature and character of the wetland system, any one or a combination of the above sources can supply adequate water to sustain wetland hydrology. Therefore, the design of a replacement wetland system should strive to exploit and/or develop as many of the above sources as may be needed to sustain the minimum amount and duration of hydrology of the planned wetland system.

General discussion

Perched or previous design? Observation of native hydric soils has provided insight into how artificially created wetland systems can be designed and constructed. Knowing the importance of soils to a successful wetlands creation project, it is imperative that soil profiles be examined and described on each site considered for wetlands construction. Of particular importance are structural and textural changes in soil horizons that may affect water movement through the soil profile. In addition, the depth to indicators of fluctuating and/or fairly constant water tables should also be noted. These observations will be helpful in assessing alternative sources of hydrology and in assessing the need to apply measures to slow water movement through the soil profile.

If evaporation rates and rates of water infiltration can be balanced against an ample surface and/or subsurface supply of water, the relative permeability of the planned soil substrate may not be critical in the wetland design. However, where hydrology is marginal, the permeability of the soil substrate and subgrade become very important considerations. Because soil permeability is directly dependent on both the size and volume of pores in a soil profile, percolation rates tend to increase as grain size increases and as soil structure becomes better defined and more angular/blocky. Conversely, as soil density increases porosity decreases; and, as a result, percolation rates also decrease. Consequently, disruption of soil structure and subgrade compaction to create a "perched" wetland system may both be beneficial in reducing soil permeability when water supplies are tentative.

Nonhydric Alluvial Soils/Floodplain Soils. Alluvial soils often have horizons that are stratified, are gravelly/sandy, or which are more pervious than others that occur in the same profile. If these more pervious horizons occur immediately under or within the design bottom elevation of the planned replacement wetland, there may be significant potential for leakage and loss of wetlands hydrology. On the other hand, if these coarser textured horizons appear to be associated with a fairly constant seasonal or regional watertable, there may be potential to exploit them as a source of wetland hydrology.

As a word of caution, however, remember that mottling (redoximorphic depletions) alone may only indicate a depth within the soil profile at which the capillary fringe of a deeper apparent watertable has risen at some time in the past. The actual watertable in alluvial soils can be predicted more accurately by monitoring, direct observation, and/or by noting the depth in the soil profile where the matrix is predominantly gray. If it is the designer's intention to intercept and exploit the apparent watertable, this distinction is well worth noting.

If it is feasible to intercept the apparent watertable the constructed wetland area should be excavated to a specified depth that will intercept the projected watertable. The replacement area should then be over-excavated by an additional 15 - 30 centimeters. Following the over-excavation, a minimum of 15 - 25 centimeters of topsoil (Ap or A horizon materials) should be placed over the entire wetland area to act as the growth medium for the planned wetland plant community (ies).

Assuming that the replacement wetland is being constructed to mirror wetland conditions found in an area that has been permitted for impact/encroachment, hydric soils may be removed from the impact area and used as part or all of the recommended topsoil application. Original hydric soils have been found to contain a wealth of naturally adapted hydrophytic "seedbank" materials that have proven to be aggressive pioneers when introduced in newly created wetland systems. On the other hand, use of hydric soils may not be advisable in some situations where a very specific plant community is being planned.

Where an apparent watertable cannot be easily intercepted, compaction of exposed native soil horizons or the installation of a clay liner may be considered (artificial liner materials are also available but may not be acceptable to all reviewing agencies). Sheeps-foot compaction of clay loam materials (Unified Classification: CL, ML, MH, CH) placed in two 15 centimeter lifts and rolled at or near optimum moisture content can produce average permeabilities of 2.2×10^{-6} cm/sec. If well protected from physical damage and freezing/thawing, clay liners frequently will allow less than 0.25 centimeters of water infiltration loss per day.

Fractured Bedrock and/or Saprolite Materials. Soils formed in or above fractured bedrock or saprolite or with shallow lithic or paralithic contact also may have potential for serious leakage problems. Here again, a 30 - 45 centimeter thick clay liner may prove to be quite effective. Figures 1 and 2 provide evidence of a successful clay liner installation in a constructed wetland near Harrisburg, PA. This installation was supervised by the author and completed late in the summer of 1992. Figure 2 shows the hydrology of the constructed wetland area early in the spring of 1993. Although it is not obvious from the photograph, planted and volunteer hydrophytes are now well established in this wetland. Substrate leakage has not been a problem, and the hydrology of the constructed wetland remains much as it is shown in Figure 2. Overall, the area appears to be evolving naturally and no additional maintenance is anticipated.

Clay Soil Cautions. The *in situ* soil structure typically found in undisturbed clay loams and other soils with high clay content often allows these soils to be better drained than expected. Many of these soils have medium to coarse and moderate to strong angular-blocky structure which tends to facilitate gravitational drainage. This soil structure is fairly common in the clay loam and silty clay loam limestone residuum soils found in parts of central Pennsylvania. However, it is also found in soils formed in glacial till, lacustrine deposits, and other fine textured parent materials. Chemical dispersants and/or compaction can be employed to destroy soil structure and may be helpful in sealing these soils to form "perched" wetland systems. However, the relative permanence of the seal created by these measures amy be affected by freezing and thawing, desiccation, and/or hydraulic pressure exerted from below (i.e., a rising regional or seasonal watertable that exerts lateral of upward vertical pressure on the compacted or dispersed clay layers). Therefore, sufficient cover to protect an area from deep drying and/or freezing is important to the longevity of the constructed wetland. If external hydraulic pressures are a concern, the area should be designed to be perennially wet.

Conclusions

Soils are critical components of constructed wetlands and should be thoroughly investigated prior to design and construction. Soils can contribute water to a constructed wetland through seasonal and regional watertables; and, due to infiltration and percolation, soils frequently are responsible for

Figure 1. Photo shows a fractured "ripable" shale in the subgrade of a wetland construction site near Harrisburg, Pennsylvania. Approximately 30% of the wetland subgrade was found to contain similar materials. Two 15 - 20 cm lifts of clay loam were placed and compacted over the base shown in this photograph. Several samples of the clay liner materials were tested and produced permeability coefficients that averaged 2.2×10^{-6} cm/sec when compacted to 95% of maximum dry density at an optimum moisture content of 17.0%. The clay liner materials were then covered with an additional 15 - 30 cm of "topsoil" materials and hydric soils salvaged from nearby wetland impact areas.

significant water losses ("export"). When necessary, soils of constructed wetlands can be manipulated to "perch" hydrology by creating slowly or very slowly permeable subgrades, or, as noted above, they can be designed to exploit perched seasonal, and regional watertables. Quantifying water inputs to and water outputs (losses/exports) from the planned wetland system will be helpful in deciding the need for measures to slow water losses through the soil substrate.

Figure 2. This photo shows the spring 1993 hydrology of the constructed wetland discussed in Figure 1 prior to aggressive establishment of the wetland plant community. The clay liner installed in 1992 appears to be functioning well. Site inundation averages 3 - 15 cm over two-thirds of the area shown, with the depth of the open water area in the background averaging 15 - 45 cm. Pioneering plants import with hydric soils and supplemental plantings are becoming well established at the time of this writing. Functions of this wetland include: nutrient filtration/uptake, sediment removal, stormwater detection, and the production of significant wildlife habitat in an urban setting (small mammal, songbird, raptor, and limited wadders, and waterfowl). Native shrubs that produce cover and food for various wildlife species are scheduled to be planted on slopes and along the wetland fringe in the fall of 1993. Following this planting, no further maintenance is expected to be necessary to ensure the viability of this wetland.

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GEOTechnical Factors in WETlands Engineering (GEOWETEN) A Prototype Knowledge - Based Expert System, S. Joseph Spigolon, Ph.D, P.E.[1] and Reda M. Bakeer, Ph.D.[2]

The proposed Wetlands Engineering Handbook contains a section on "Engineering for Wetlands Substrate." All of the proposed topics require geotechnical engineering expertise for their implementation. First, a subsurface investigation must be made to determine the character and suitability of the existing substrate soils. The existing soils must be *validly* identified, described, and possibly classified according to a meaningful classification system. If earthwork or soils handling is indicated for the project, then plans and specifications must be prepared for the excavation of upland soils or a borrow area, for the transport of the soils to a fill or disposal area, and the placement of the materials in an area fill, a compacted dike, or a disposal area. The soils handling processes of excavation, transportation, and deposition (fill or disposal) may be done by using mechanical or hydraulic equipment and methods, or by some combination of these methods.

Expert guidance in the geotechnical engineering aspects of the project is not always readily available to the engineers, scientists, and constructors who are involved, particularly on smaller projects. Inexperienced persons invariably need expert guidance or even formal instruction, and experienced persons can always benefit from peer review. The project-related knowledge of experienced geotechnical engineers is often not adequately transferred and is usually lost on retirement or position change. Knowledge-Based Expert System (KBES) programs record the knowledge of experts in a given field in a readily accessible knowledge base and, therefore, can provide the necessary guidance to accomplish these aims.

Background

The GEOWETEN group of programs is being prepared under contract with the U.S. Army Corps of Engineers' Wetlands Research Program (WRP). The principal investigator is Mr. Roy E. Leach, Geotechnical Laboratory, U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, MS. The knowledge contained in the GEOWETEN programs is based, in large part, on lessons learned in other WES research programs such as the Dredged Material Research Program (DMRP), the Dredging Research Program (DRP), and the Environmental Effects of Dredging Program (EEDP).

The following discussion describes a group of KBES programs presently being developed for the purpose of providing guidance in various aspects of

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wetlands geotechnical engineering. The programs will be concerned with (a) planning effective geotechnical investigations of the substrate soils, (b) identifying and describing the substrate soils and classifying them according to a meaningful system, and (c) evaluating the suitability of various types of equipment 'nd methods for use in soils handling situations for a soil of given character and description.

Knowledge Based Expert System

A Knowledge Based Expert System (KBES) uses expert-derived rules for its conclusions. The rules can incorporate and process judgement, experience, empirical rules of thumb, intuition, and other expertise as well as proven functional relationships and experimental evidence (Maher and Allen, 1987). The rules are recorded in one or more knowledge bases, using everyday English language and/or numbers, in the form of IF - THEN statements. The control system (inference engine) for searching the knowledge base of a KBES is independent of the knowledge base, permitting simple modifications and additions to the answers contained in the knowledge base without modifying the program.

In data-driven, or forward chaining, expert systems, such as those in the GEOWETEN group, all of the necessary IF-statements are first gathered into a problem "context." During a consultation session, a KBES asks a series of questions. The logic of the IF-conditions may include the modifiers AND, OR, or NOT, and the arguments may be either English words, or phrases, or numbers. For each question, the user selects from a menu containing an exhaustive set of valid answers, sometimes limited to a simple YES or NO. The menu may even include a term such as "Unknown" or "Don't know." The path through the matrix of questions is not pre-determined; rather, the path depends on each context-specific question and on the user's reply, which then leads to the next appropriate question. The complete set of answers to the posed questions constitutes the context, or antecedents, of the problem. The THEN-part contains a group of conclusions, actions, recommendations, or decisions. A rule is fired (satisfied) once all the necessary IF conditions are fulfilled and, accordingly, the THEN-part becomes true.

At any time during the guidance sessions, the user may view a text discussion of any of an extensive list of pertinent topics and then return to the guidance session. The discussions present the rationale for the rules and contain other topics that may be helpful in understanding the guidance.

Two microcomputer versions of GEOWETEN are being developed. One will operate in the conventional MS-DOS environment. The other version will run under the Microsoft Windows graphical environment. The control program, the information and questions on the user-interaction screens, the knowledge base, and the discussion texts for both versions will be identical. Only the display screen appearance will differ; the DOS version uses the standard DOS character-based display and the Windows version uses a graphical

display, which will permit the display of drawings and photographs. Both versions of GEOWETEN will be user friendly and support mouse input. This will practically eliminate the need for the user to type words for data input during guidance sessions; only numbers and mouse-pointer selection from input menus will be needed. This is expected to greatly facilitate the use of the system by non-typists.

The rules developed for GEOWETEN programs will initially represent the personal knowledge and expertise of the authors, developed through professional experiences, research studies, and personal interviews with experts and, therefore, will reflect their personal biases. It is most desirable that the rules be critically reviewed by other geotechnical engineering and earthwork construction experts and expanded or modified, as needed. In the development of the ideal knowledge base, there are multiple experts who either reinforce each other or present valid alternate solutions to problems.

In effect, a KBES is a technical report that has been placed into a computerized question-and-answer format. All of the information could, alternatively, be contained in a written and published report. However, a computer-based KBES has certain advantages over the printed document:

a. The sequence of questions is expert-guided for each specific task. The user provides answers to the questions from an exhaustive, but limited, set of correctly phrased answers, using standard terminology. When all appropriate questions have been asked and answered, the knowledge base is searched for all valid conclusions that can be derived from the problem context. The conclusions are presented on screen and, in some instances, can be printed.

b. It is simpler, easier, and faster to use than a published report. Pages appear on screen quickly rather than requiring hunting for the contents or index, then searching for the exact pages.

c. The knowledge recorded in the knowledge base can be easily edited and modified to accommodate new research findings or local experiences, permitting the issuance of easily-made updated versions of the KBES on microcomputer diskettes. The text information contained in the readily-accessible "Discussion" topics can also be easily added to or changed. This does not imply that the user will be able to modify the control program or the knowledge base directly. Only the official, development version under the control of the developers or the program administrators will be capable of being modified.

d. For recording knowledge of a strictly local or regional interest, a separate "LOCAL INFO" discussion text knowledge base can be readily established and locally updated. Some organizations could benefit by placing the latest version of popular programs on a Local Area Network. In some instances, a national "bulletin board" system could be

e. used to distribute the revised versions of the programs.

The Geoweten Modules

At present, it is intended that three independent modules will be included in the overall GEOtechnical factors in WETlands Engineering (GEOWETEN) group:

a. **GEOtechnical SITE investigation methods (GEOSITE)** provides guidance for the selection of suitable sampling methods, strength testing methods, and material properties tests. The program considers only one soil type and one exploration site at a time. In wetlands projects there may only be one soil type per location. Using a personal (non-computerized) evaluation of this information for the entire project, the planning and execution of an appropriate and valid site investigation involving several exploration sites can be accomplished on purpose.

b. **GEOtechnical CLASSification of Soils (GEOCLASS)** guides the user through the field and/or laboratory identification of soil samples, the description of the substrate soil samples in standardized terms, and the classification of the soils. Classification may be made in any of several Wetlands Engineering compatible classification systems. The data may also be recorded in a standard database for further use such as computer-aided preparation of boring logs and subsurface profiles.

c. **WETlands earthwork CONSTruction (WETCONST)** guides the engineer/designer in the design/plans/specifications of a project involving earthwork, or soils handling. Guidance in the suitability of methods and equipment for excavation, transport, and fill placement is given for soils having any in situ characteristics. This requires that *valid and appropriate* geotechnical descriptions and classifications of the site substrate soils be obtained. The GEOSITE and GEOCLASS programs can provide guidance for obtaining the necessary geotechnical data.

The sequence of geotechnical engineering events, and the utility of the GEOWETEN group of programs, in a wetlands project will normally proceed as follows (Spigolon, 1993; Spigolon and Fowler, 1990):

a. All of the pre-existing (prior) geotechnical and geological information about the substrate at the proposed site is reviewed. This includes published literature, maps, records from projects in the area, local experiences, and observation of the surface features of the site. This may be augmented, as appropriate, with geophysical exploration data. The pre-existing information is used to develop a preliminary estimate of the subsurface geotechnical profile.

b. Based on all the pre-existing geotechnical information about the site, a site exploration strategy is developed, including the number and locations of exploration sites. This decision is made personally (non-computerized) based on the expected variability of the site stratification and a number of other factors, including comparison of costs. There is not, at the present time, a suitable, general KBES for providing expert guidance for this decision.

c. During the planning for each individual exploration site, the **GEOSITE** program provides guidance for selecting suitable soil sampling and testing methods, a suitable sample/test access method, and an exploration work platform based on the soils expected to be found at that site.

d. During the subsurface investigation at each exploration site, the **GEOCLASS** program provides guidance for identifying, describing, and classifying the samples that are retrieved. **GEOCLASS** is also used during sample review in the office/laboratory and during boring log preparation. After completion of the site exploration program, a complete set of boring logs is prepared, containing suitable and valid sample descriptions and classifications.

e. During the planning and execution of the soils handling aspects of a wetlands project, the **WETCONST** program is used to provide guidance in evaluating (1) the soils handling properties of each of the sediment types encountered during the site investigation and (2) the suitability of various types of excavation, transport, and placement equipment and methods.

Geotechnical Site Investigation Methods (GEOSITE)

GEOSITE is intended to be used by a civil engineer, an engineering geologist, or any other engineer or scientist familiar with basic geotechnical site investigation and testing methods. The system is not intended to be a primary teaching tool, although it could serve as a reference or as a refresher for experienced persons or as an aid in training inexperienced personnel. It would take much more than this program has to offer to teach geotechnical engineering testing methods to anyone without the necessary educational background.

The consultation process of GEOSITE starts with the assumption that the stratification is moderately well known. It is reasonable to require this assumption; this demands that every effort be made to assemble and evaluate the pre-existing information and to use geophysical surveys wherever they are feasible. The choice of a general soil type from a layer or deposit from the expected profile causes GEOSITE to limit its consultation process only to those topics that apply to the specific soil type and to exclude all others. If the substrate profile expectation is found to be wrong, then a return to the program for re-evaluation with the updated information will be necessary.

After the user indicates a general soil type, selected from a menu, GEOSITE presents all sediment sampling methods that are appropriate to the specific sediment type using the following rule structure:

IF the general soil type is:
THEN the suitable sampler types are:

A listing of all generic sampling devices is shown. The suitable sampler types are recommended without ranking and the superiority of one method over another, if it exists, is discussed in the "discussion" texts. Sampling devices that are not appropriate to the soil type are marked "NOT SUITABLE." Next, the user chooses one of the sampling methods for further guidance. GEOSITE displays all of the strength testing methods, field or laboratory, that are appropriate for that sediment type and sampler using the following rule structure:

IF the general soil type is:
AND the sampling device is:
THEN the suitable strength testing methods are:

The listing of strength test methods includes all generic methods in no specific order. All suitable methods are rated according to "confidence" and "utility." A confidence factor (CF) indicates the relative accuracy and precision of a strength testing method compared to the other methods in the group. A utility factor (UF) indicates the relative efficiency of a testing device in terms of time and money cost, including difficulty of mobilization of equipment at the site, time for making a test, complexity of the test method, and the need for using two separate devices, one for securing the sample, the other for the test. At any time, and for as many times as desired, the user may return to the previous "sampler suitability" screen for guidance on a different sampling device and suitable strength test methods. Then, for any chosen combination of sediment type, sampler, and strength test device, GEOSITE advises on the suitability of various methods for accessing the sampling/testing depth using the following rule structure:

IF the general soil type is;
AND the sampling device is:
AND the strength testing method is:
THEN the suitability of various methods of accessing the sampling/testing depth is:

Finally, guidance is given on suitable material properties tests using the following rule structure:

IF the general soil type is:
THEN the suitability of various materials properties tests, field and/or laboratory, is:

Geotechnical Classification of Soils (GEOCLASS)

The objective of GEOCLASS is to provide guidance in the field and laboratory identification, description, and classification of soils, in a consistent manner, using a consistent and standard language. Only a limited number of acceptable and appropriate descriptors is permitted for each property. The program makes all necessary calculations, checks for internal consistency of the data, and develops a word description of the sample and a classification according to the Unified Soil Classification System (USCS/ASTM) and/or the U.S. Department of Agriculture (USDA) classification system, and may be modified to include other standard classification systems. The program also provides for the analysis and recording of the data in a standardized project database that can be accessed directly by boring log and other graphic data presentation programs. A complete database record is developed and maintained of every sample type, field strength test, visual-manual observation, and laboratory test made of each sample.

The GEOCLASS module is primarily expected to be used by engineering soils technicians with some geotechnical training, relatively inexperienced civil engineers or engineering geologists,or experienced geotechnical engineers or engineering geologists who will use this module primarily as an electronic data recording system. It may even be possible for persons with non-engineering scientific training to use GEOCLASS effectively.

After the appropriate information source is identified, GEOCLASS uses a series of screens to prompt the user to make the necessary observations and/or tests, to select the appropriate observation or test descriptor from a menu, and to record the sample information. The observation and/or test data for each individual sample are entered into the database at any one of three times and locations corresponding to the natural flow of information gathering:

a. At the field sampling and testing site. Observations and tests that are made and recorded include (1) simple visual/manual manipulation tests of the soil sample (2) field in-situ strength (compactness or consistency), permeability, or other tests. This is the same type and form of information now maintained in a hand-written field boring log.

b. During the office/laboratory review of the field logs and samples, preparatory to assigning laboratory tests. A record is also made of visual-manual similarity of the sample with another sample whose characteristics are known or will be formally tested.

c. Following completion of standard, formal laboratory tests on selected samples.

The GEOCLASS computer database is meant to take the place of many of the paper records now being maintained. If all samples in all borings (or pits) on a project are recorded in similar fashion, the data for developing formal boring logs and a subsurface profile will be present in electronic storage, ready

for manipulation. There now exists a few specialized programs for manipulating this type of databased information into useful summaries. The information in this form may even be supplied to all concerned groups, owner, engineer, designer, and prospective contractors, in the form of a database file on a microcomputer diskette.

Wetlands Earthwork Construction (WETCONST)

The suitability of various soil handling methods and equipment for use at a wetland site is determined by (1) the trafficability of the surface of the borrow area, the transport roadway, and the deposition site, (2) the quantity, location, and engineering characteristics of the soils to be moved, (3) the average grade of the transport roadway, and (4) the location and specifications for wetland site deposition. Excavation, transport, and deposition of a soil may be done by mechanical or hydraulic equipment and methods. Mechanical methods include all types of mechanical excavators and earth moving machines. Hydraulic methods typically involve some form of dredging technology for forming and pumping a soil-water slurry. Virtually all soil types can be handled by either method.

WETCONST is intended to serve the engineer, planner, or earthwork contractor as a personal geotechnical engineering and construction expert consultant. The program is limited to providing guidance (1) in the interpretation of geotechnical soil properties data, of soils that are to be handled, for estimating their earthwork construction properties and (2) for evaluating the suitability of various types of earthwork construction equipment for the project soils and for the other significant site conditions summarized above.

It is assumed by WETCONST that the geotechnical description of the sediment to be dredged is given in project documents in the Unified Soil Classification System (USCS) format (USAEWES 1953, ASTM 1992) or can be readily converted to that format. The USCS description may be supplemented with other needed information such as in-situ compactness or consistency data or as-placed permeability. WETCONST prompts the user for the geotechnical data needed for evaluation of the soil handling characteristics.

The rules for evaluation of a soil's handling properties that are used in WETCONST are in the following form to establish the engineering properties of the layer or deposit being considered (NOTE: the following are used as appropriate to the sediment type):

IF the primary soil type is:
  AND the main name and USCS classification are:
  AND other pertinent in-situ soil geotechnical properties are:

THEN the soil's excavation properties are:
  AND the soil's transport properties are:
  AND the soil's deposition properties are:

Then, the suitability of various types of soils handling equipment and methods requires definition of the surficial characteristics of the specific site:

IF the engineering characteristics of the soil deposit are:
AND the quantity and location of the soils to be moved are:
AND the trafficability of the surface of the borrow area is:
AND the trafficability of the transport roadway is:
AND the trafficability of the deposition site is:
AND the average grade of the transport roadway is:
AND the location and specifications for wetland site deposition are:

THEN the suitability of various types of excavating machinery and methods is:
AND the suitability of various types of transport equipment and methods is:
AND the suitability of various types of compaction methods and equipment is:

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Lost Lake Restoration and Wetlands Mitigation Monitoring, Preliminary Report, Harold Ornes and Tanya Youngblood[1], Halkard E. Mackey, Jr., Ph. D., and R. Steve Riley[2]

Introduction

A cleanup and restoration project of a Carolina Bay, Lost Lake, was undertaken at the U.S. Department of Energy's Savannah River Site near Aiken, SC from 1989 to 1990. One purpose of this project was to develop a strategy and implementation for the restoration of Lost Lake. Specifically, after cleanup of the bay, efforts included improvement of biological diversity with native species and erosion control.

Carolina Bays commonly have an impervious clay layer beneath the soil surface, consequently the hydrologic regime depends on local precipitation patterns (Lide, 1991; Kirkman, 1992; Sharitz and Gibbons, 1982). Individual bays may be occasionally flooded, seasonally flooded, or continually flooded. These wetlands tend to have deeper water levels in winter, relative to levels in summer (Kirkman and Sharitz, 1993). The vegetation of these bays are intricately related to hydroperiod (Kirkman, 1992). Many bays are dominated by a mixture of sedges, including *Panicum hemitomon*, *Manisuris rugosa*, and *Leersia hexandra*, which usually occur in nearly monospecific stands that change in area and community dominance with changing water conditions (Kirkman, 1992). Other bays have been reported to have concentric vegetation zones ranging from xeric to hydric. The upland concentric circle of vegetation may be dominated by trees such as *Pinus taeda* and *P. palustris*, *Nyssa sylvatica*, *Quercus marilandica*, and *Liquidambar styraciflua*. Also in this zone there may be several shrubs (*Rhus copallina*, *Ilex glabra*, and *Persea borbonia*). Inside the woody zone may be an herbaceous band including the grasses *Andropogon virginicus*, *Aristida affinis*, and *Panicum* sp. In the water may be *Nymphaea odorata* and *Nymphoides aquaticum* (Kelley & Batson, 1955).

At Lost Lake, the hydrologic regime was such that lake levels were from 1/2 to 1/3 below capacity during the period from May 1992 through December 1992. According to Kirkman (1992) the hydrologic regime of a wetland is the most important factor that controls patterns of vegetation. An example of this hydrologic influence during wet periods is that anaerobic conditions may prevent normal root respiration in most plants and strongly affect the availability of nutrients (Ernst, 1990; Mitsch and Gosselink, 1986; Ponnamperuma, 1972). Schalles, et al. (1989), reported very low O_2 levels in bottom strata of several Carolina Bays at the Savannah River Site. Intuitively, one can imagine how during dry times plant growth could be limited. Kirkman (1992) concluded that it was during extremes of the hydrologic regime (*i.e.* very wet or very dry

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conditions) that recruitment from the seed bank becomes a more significant factor influencing vegetation change. Species diversity and density of seed banks of Carolina Bays are among the highest for wetlands reported, although, these seed banks do not necessarily reflect standing vegetation (Kirkman, 1992).

Lost Lake probably does not perfectly fit the Bathtub Model described by Lide (1991), where there are no surface inlets or outlets, no ground water exchanges, and no overland flow. Lost Lake is, however, a shallow depression with hydrological regimes that fluctuate in response to rainfall, a characteristic of Carolina Bays (Sharitz and Gibbons, 1982).

The present project involved a monitoring effort to assess whether or not restoration efforts were successful at Lost Lake.

Lost Lake is approximately 11.3 hectares when full with a maximum depth of 1.22 meters. From the early 1940s to the early 1950s, Lost Lake was drained and used for agricultural purposes. After the Department of Energy removed the land from farming in the early 1950s, Lost Lake began to refill and function as a wetland. During the period of 1950s to 1984 Lost Lake received quantities of inorganic contaminants (primarily heavy metals), solvents, and cleaning fluids, from the M-Area settling basin located on the Lost Lake watershed. One aspect of a closure plan for the M-Area settling basin (approved by SCDHEC in July of 1987) was to restore the degraded bay to a "natural wetland system" (Gladden, et al., 1992).

Materials and Methods

In 1988 and 1989 vegetation in the bay was burned and the residual ash removed. After the lake was drained, the remaining vegetation and soil were removed (ranging from a depth of 2 to 12 inches). The Lost Lake basin was divided into three elevation regions based on soil characterization and contamination levels: the top two inches of soil was removed from the 338 to 340 msl contour; the top 6 inches of soil was removed from the 336 to 338 ft msl contours, and the top 12 inches was removed from the area below 336 ft msl.

In December, 1990 the water level was lowered to facilitate soil treatments conducted in January, 1991. The bay was divided into eight treatment zones to receive 4 treatments in duplicate. The four treatments were duplicated such that each occurred in an area of greater and lesser soil removal.

Treatment zones around the bay consisted of the following: (1) no treatment; (2) fertilizer (300 lbs/ac), gypsum (calcium sulfate dihydrate, 2 tons/ac), and plantings; (3) sub-soiling, disking, fertilizer, gypsum, and plantings; and (4) topsoil (upland Orangeburg soil), sub-soiling, disking, fertilizer, gypsum, and planting. The treatments were compounded in that one of the duplicate treatments received extensive soil removal (A treatment zones) during the

initial cleanup phase and one of the duplicate treatments received minimal soil removal (B treatment zones).

During the period January through April, 1991, each of the eight treatment zones were planted with eight species of wetland plants. Four sizes of experimental plots were used in each zone: 35, 2 x 2 m^2 plots; 7, 3 x 10 m^2 plots; 7, 5 x 10 m^2 plots; and 7, 10 x 10 m^2 plots.

Planted species

In the 35 2 x 2 plots, a total of 270 individuals of each of the following species were planted: *Pontederia cordata, Eleocharis* sp. (both from Par Pond on the SRS site), *Panicum hemitomon,* and *Scirpus cyperinus* (taken from a nearby Carolina Bay). Soil plugs (the top 2 or 3 inches of a vegetated mud bank) also were collected from a nearby Carolina Bay for the purpose of introducing seed bank sources. In the 7, 3 x 10 plots, 570 individuals of each of the above species were planted (except *Sagittaria latifolia,* which was not available in sufficient quantities at S.R.S. to allow transplanting without depleting the donor stock). In the 7, 5 x 10 plots, 1026 individuals of each of the above species were planted, except for *Sagittaria latifolia.* In the 5, 10 x 10 plots, 1458 individuals of *Nelumbo lutea* (as germinated seeds) and *Nymphaea odorata* were planted.

Monitoring efforts

Although low-level aerial imagery and satellite imagery are being collected, our study focused on traditional ground measurements of plant identification, density, percent cover, percent survival, species area curves, and hydrology data (rainfall and lake-level readings). Both planted species and naturally occurring successional species were monitored.

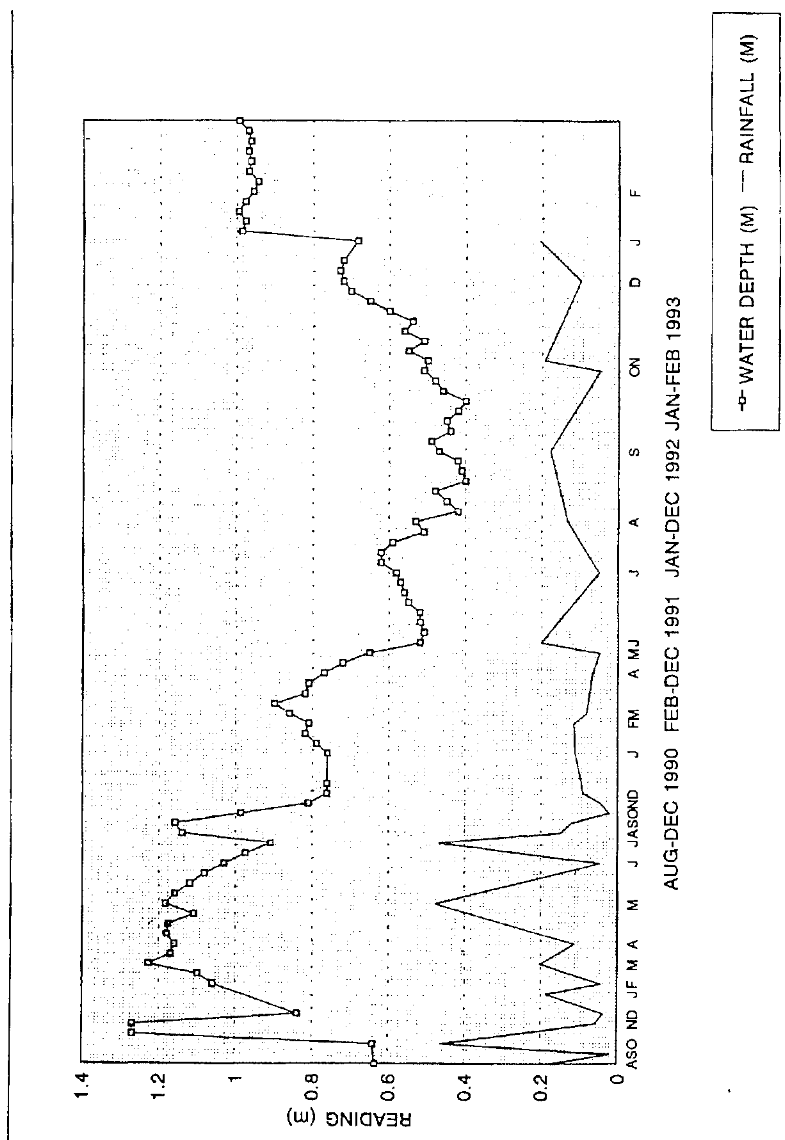
Results

Non-planted vegetation status nineteen months after extensive or minimal soil removal, soil treatments, and plantings

The overall hydrology of Lost Lake was such that during the summer of 1991 the water level of the bay was normal. During the summer of 1992 the water level at Lost Lake was lower due to dryer weather conditions. (Figure 1).

Fig. 1 WATER LEVEL AT LOST LAKE

GAUGE READINGS & MONTHLY RAINFALL



1990-1991-1992-1993

Treatments 1A (extensive soil removal) and 1B (minimal soil removal): no treatments, control zones

1A. In the 35, 2 x 2 plots, the hydrology was such that they were dry during the 1992 monitoring period. Grasses occurred in all the plots and averaged 98% cover. *Polygonum* sp. occurred in 10 of the 35 plots and averaged 15% cover. *Eupatorium* occurred in 5 plots and averaged 17% cover. *Typha latifolia* occurred in only 2 of the 35 plots and averaged 3% cover. The extensive soil removal zone appeared to have less diversity of vegetation than the minimal soil removal zone. The average number of non-planted species per 2 x 2 plot was 1.5. The cumulative number of non-planted species in the 2 x 2 plots was 5 for 1992.

In the 7, 3 x 10 plots grasses occurred in all plots and averaged 69% cover. *Typha* and medium herbs both occurred in 2 of the 7 plots and averaged 50% and 10% cover respectively. *Polygonum* occurred in one of the 7 plots and averaged 10% cover.

In the 7, 5 x 10 plots grasses occurred in all plots and averaged 82% cover. *Typha* and medium herbs both occurred in 2 of the 7 plots and averaged 10% and 18% cover, respectively. *Eleocharis acicularis* occurred in one of the 7 plots with 10% cover.

In the 7, 10 x 10 plots *Eleocharis acicularis* occurred in 6 plots averaging 52% cover. Grasses and *Hydrocotyle* occurred in 6 plots averaging 10 and 20% cover respectively. *Potamogeton* sp. occurred in 4 plots averaging 16% cover. *Cyperus* occurred in 4 of plots averaging 11% cover.

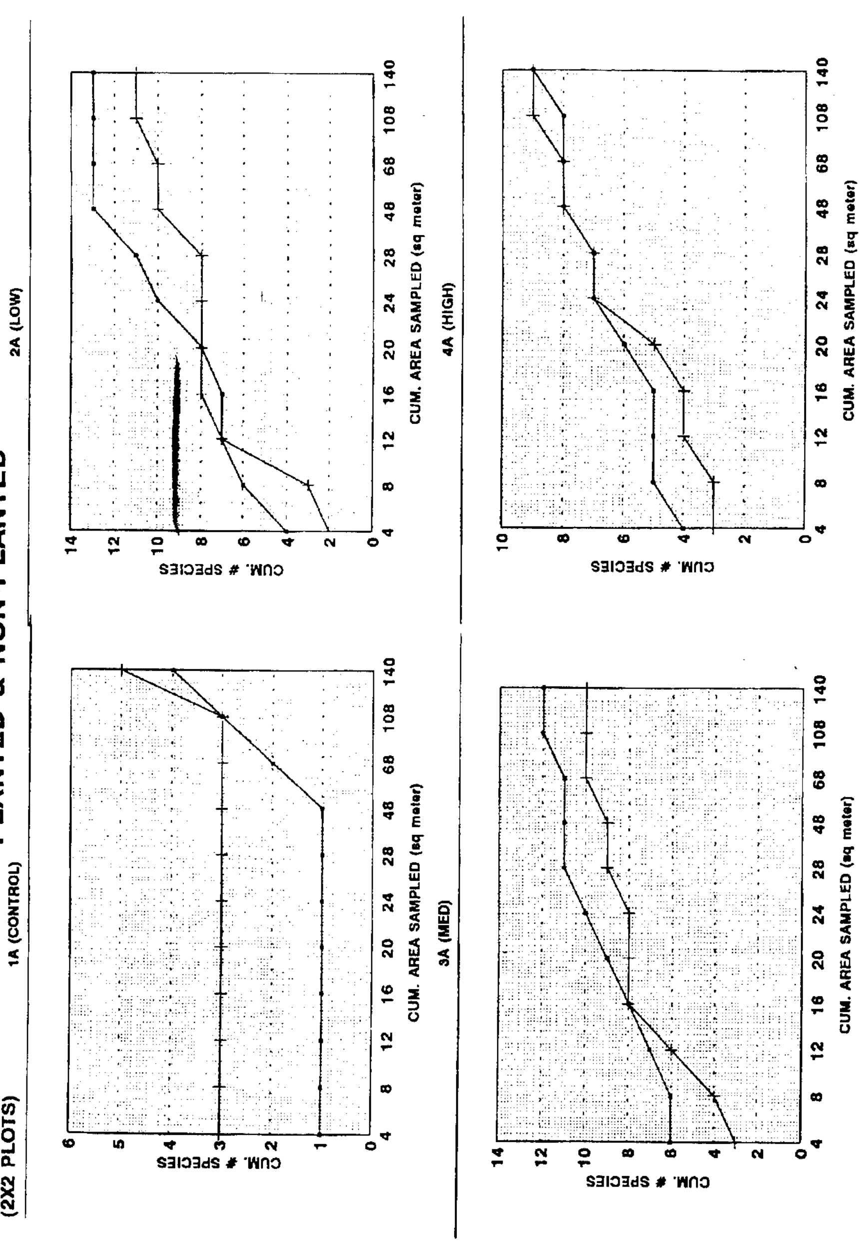
1B. In the 35, 2 x 2 plots the hydrology was such that the higher elevations were dry and the lakeside elevations ranged from 1.0 to 3.0 cm water depth. Grasses were dominate in this zone. They occurred in all 35 plots and averaged 80% cover. *Polygonum* sp. occurred in 10 of the 35 plots and averaged 50% cover. *Typha* occurred in 27 of the 35 plots and averaged 40% cover. *Eleocharis acicularis* occurred in 18 of 35 plots and averaged 8% cover. *Eupatorium* occurred in 8 plots and averaged 12 % cover. The non-planted species diversity was greater in the minimal soil removal zone than in the extensive soil removal zone, averaging 4 species per plot. The cumulative number of non-planted species was 7 for 1992 (Figure 3).

In the 7, 3 x 10 plots grasses occurred in all plots and averaged 74% cover. *Typha* and *Eleocharis acicularis* both occurred in 4 of the 7 plots and averaged 18% and 14% cover, respectively.

In the 7, 5 x 10 plots grasses and *Typha* occurred in all plots and averaged 46% and 24% cover, respectively. Medium and tall herbs occurred in 5 of the 7 plots and averaged 15% cover. *Eleocharis* occurred in 4 of the 7 plots and averaged 15% cover.

EXTENSIVE SOIL REMOV.
(2X2 PLOTS)

Fig. 2 SPECIES AREA CURVES
PLANTED & NON-PLANTED



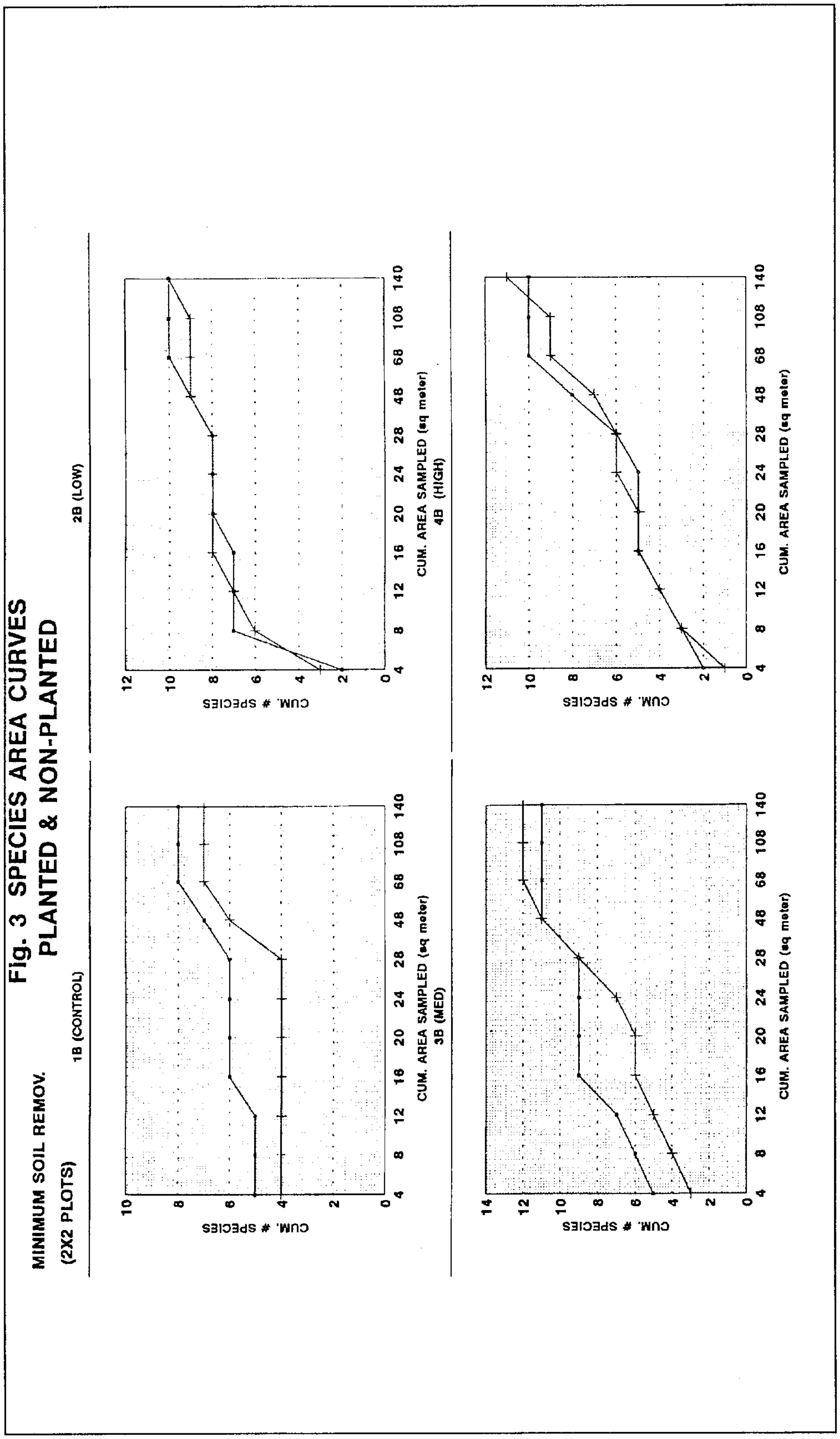


Fig. 3 SPECIES AREA CURVES
PLANTED & NON-PLANTED
MINIMUM SOIL REMOV.
(2X2 PLOTS)
1B (CONTROL)
2B (LOW)
3B (MED)
4B (HIGH)
CUM. # SPECIES
CUM. AREA SAMPLED (sq meter)

In the 7, 10 x 10 plots *Typha* occurred in 5 plots averaging 11% cover and *Eleocharis acicularis* occurred in 5 plots averaging 27% cover plants occurred. Grasses occurred in only 2 plots averaging 5% cover.

Treatments 2A (extensive soil removal) and 2B (minimal soil removal): fertilizer, gypsum, and plantings

2A. In the 2 x 2 plots the hydrology was such that they were dry in 1992. Grasses occurred in 27 of the 35 plots and averaged 50% cover. *Eleocharis acicularis*, was in 9 plots and averaged 40% cover. *Typha* was in 12 plots and averaged 35% cover. *Eupatorium* was in 14 plots and averaged 30% cover. *Polygonum* was in 8 plots and averaged 15% cover. The species diversity averaged 2 non-planted species per 2 x 2 plot. The cumulative number of non-planted species was 7 for 1992. The cumulative number of planted and non-planted species was 11 for 1992 (Fig. 2).

In the 3 x 10 plots grasses occurred in all 7 plots and averaged 49% cover. Medium and tall miscellaneous herbs occurred in 4 of the 7 plots and averaged 26% cover. *Polygonum* occurred in 3 of the 7 plots and averaged 25% cover. *Typha* also occurred in 3 of the 7 plots and averaged 10% cover.

In the 5 x 10 plots grasses occurred in all of the 7 plots and averaged 67 % cover. Medium and tall herbs occurred in 3 of the 7 plots and averaged 17% cover. *Eleocharis acicularis* occurred in 2 of the 7 plots and averaged 10% cover. *Typha* also occurred in 2 of the 7 plots and averaged 6% cover.

In the 7, 10 x 10 plots *Typha* occurred in 4 plots and averaged 41% cover. *Eleocharis acicularis* and grasses occurred in 7 plots averaging 22% and 49% cover respectively.

2B. In the 2 x 2 plots the hydrology was such that moisture ranged from dry at the higher elevations to 3 cm water depth at the lakeside, lower elevations. *Typha* occurred in every plot and averaged 50% cover. *Eleocharis acicularis* was in 31 of 35 plots and averaged 15% cover. *Polygonum* was in 21 plots and averaged 15% cover. *Eupatorium* was in 9 plots and averaged 11% cover. Grasses were only in 3 plots and averaged 15% cover. The species diversity averaged 3 non-planted species for each 2 x 2 plot. The cumulative number of non-planted species was 6 for 1992. The cumulative number of planted and non-planted species for all the 2 x 2 plots in this zone was 10 (Figure 3).

In the 7, 3 x 10 plots *Typha* occurred in all plots and averaged 46% cover. Medium and tall herbs occurred in 6 of the 7 plots with 18% cover. Grasses occurred in 4 of the 7 plots and averaged 16 % cover. *Setaria* occurred in 4 of the 7 plots and averaged 10 % cover. *Liquidambar styraciflua* occurred in 2 plots.

In the 7, 5 x 10 plots *Typha* occurred in all plots and averaged 47% cover. Medium and tall herbs occurred in 6 of the 7 plots and averaged 28% cover. Grasses and *Eleocharis acicularis* each occurred in 1 of the 7 plots with 30% and 10% cover, respectively.

In the 7, 10 x 10 plots grasses occurred in all 7 plots averaging 41% cover. *Setaria sp.* occurred in 5 plots averaging 41% cover. Medium herbs occurred in 2 plots averaging 35% cover. *Typha* occurred in 4 plots averaging 19% cover and *Hydrocotyle* occurred in 1 plot averaging 10% cover.

Treatment 3A (extensive soil removal) and 3B (minimal soil removal): subsoiling, disking, fertilizer, gypsum, and plantings

3A. In the 2 x 2 plots the hydrology was such that they were dry in 1992. *Typha* occurred in 28 of the 35 plots and averaged 30% cover. *Eupatorium* occurred in 29 plots and averaged 30% cover. Grasses occurred in 14 plots and averaged 38% cover. *Eleocharis acicularis* occurred in 12 plots and averaged 13% cover. Seventeen of the 35 plots had significant bare areas and averaged 12% barren. The species diversity averaged 2.4 non-planted species per 2 x 2 plot. The cumulative number of non-planted species was 5 for 1992. The cumulative number of planted and non-planted species found in all of the 2 x 2 plots in this treatment was 10 (Fig. 2).

In the 7, 3 x 10 plots *Typha* occurred in all plots and averaged 64% cover. Medium and tall herbs occurred in 6 of the 7 plots and averaged 18% cover.

In the 7, 5 x 10 plots *Typha* occurred in 6 plots and averaged 48% cover. Medium and tall herbs occurred in all 7 plots and averaged 26% cover. Grasses occurred in 6 of the 7 plots and averaged 17% cover. *Eleocharis acicularis* occurred in 3 of the 7 plots and averaged 12% cover.

In the 7, 10 x 10 plots grasses occurred in 6 plots averaging 39% cover. *Typha* and *Eleocharis acicularis* occurred in 5 plots and averaged 20% and 39% cover respectively. *Hydrocotyle* occurred in 2 plots averaging 10% cover and *Ludwigia* occurred in 1 plot with 30% cover.

3B. In the 2 x 2 plots, the hydrology was such that the plots were dry except for 3 of the 35 plots. *Typha* occurred in 26 of 35 plots and averaged 33% cover. *Eleocharis acicularis* occurred in 22 plots and averaged 14% cover. Grasses occurred in 19 plots and averaged 36% cover. *Polygonum* sp. occurred in 7 of the 35 plots and averaged 10% cover. *Setaria* occurred in 10 plots and averaged 10.5% cover. *Eupatorium* occurred in 7 plots and averaged 28.6% cover. The species diversity averaged 2.8 non-planted species per 2 x 2 plot. The cumulative number of non-planted species was 7 for 1992. The cumulative number of planted and non-planted species in the 2 x 2 plots was 12 (Fig. 3).

In the 7, 3 x 10 plots grasses occurred in 6 plots and averaged 42% cover. *Typha* occurred in 5 of the 7 plots and averaged 35% cover. Medium and tall herbs occurred in 6 of the 7 plots and averaged 18% cover. *Eleocharis acicularis* and *Polygonum* sp. occurred in 1 plot each and averaged 10%, respectively. *Liquidambar styraciflua* occurred in 1 plot.

In the 7, 5 x 10 plots *Typha* occurred in all plots and averaged 41% cover. Giant fox tail occurred in 5 of the 7 plots and averaged 15% cover. *Eleocharis acicularis* occurred in 4 of the 7 plots and averaged 14% cover. Medium and tall herbs occurred in 3 of the 7 plots and averaged 17% cover.

In the 7, 10 x 10 plots grasses occurred in 6 plots averaging 23% cover. *Eleocharis acicularis* occurred in 5 plots averaging 56% cover. *Typha* occurred in 4 plots and averaged 10% cover. *Polygonum* occurred in 3 plots and averaged 8% cover while *Hydrocotyle* occurred in 2 plots and averaged 27% cover.

Treatment 4A (extensive soil removal) and 4B (minimal soil removal): subsoiling, disking, topsoil, fertilizing, and gypsum

4A. In the 2 x 2 plots, hydrology was such that all the plots were dry in 1992. *Typha* occurred in all of the 35 plots and averaged 41% cover. *Eleocharis acicularis* occurred in 18 of the 35 plots and averaged 17% cover. Grasses occurred in 11 plots and averaged 26% cover. *Eupatorium* occurred in 8 plots and averaged 5.4 % cover. The species diversity averaged 2.2 non-planted species per 2 x 2 plot. The cumulative number of non-planted species was 4 for 1992. The cumulative number of planted and non-planted species was 9 for 1992 (Fig. 2).

In the 7, 3 x 10 plots *Typha* occurred in all plots and averaged 63% cover. *Eleocharis acicularis* occurred in 5 of the 7 plots and averaged 14% cover. Grasses occurred in 2 of the 7 plots and averaged 5% cover.

In the 7, 5 x 10 plots *Typha* occurred in 6 plots and averaged 58% cover. Grasses occurred in 6 of the 7 plots and averaged 38% cover.

In the 7, 10 x 10 plots *Typha* occurred in 5 plots averaging 20% cover. *Eleocharis acicularis* occurred in 5 plots averaging 33% cover. Grasses occurred in 6 plots averaging 18% cover. *Potamogeton* sp. occurred in 2 plots averaging 20% cover.

4B. In the 2 x 2 plots the hydrology was such that all of the plots were dry in 1992. *Typha* occurred in 31 of the 35 plots and averaged 37% cover. Grasses occurred in 25 plots and averaged 41 % cover. *Eleocharis acicularis* occurred in 2 plots and averaged 27.5 % cover. *Polygonum* sp occurred in 5 plots and averaged 13% cover. *Eupatorium* occurred in 6 plots and averaged 8% cover. The species diversity averaged 2.0 non-planted species per 2 x 2 plot. The cumulative number of non-planted species was 6 for 1992. The

cumulative number of planted and non-planted species was 11 for 1992 (Fig. 3).

In the 7, 3 x 10 plots grasses occurred in 6 plots and averaged 48% cover. Tall herbs occurred in 5 of the 7 plots and averaged 19% cover. *Typha* occurred in 4 of the 7 plots and averaged 23% cover.

In the 7, 5 x 10 plots *Typha* occurred in 6 plots and averaged 22% cover. Tall herbs and grasses both occurred in 5 of the 7 plots and averaged 25 and 42% cover, respectively. *Polygonum* occurred in one of the 7 plots and averaged 10% cover.

In the 7, 10 x 10 plots grasses dominated occurring in 5 plots with 54% cover. 46% of the area was open water with bare area.

Planted vegetation status nineteen months after extensive or minimal soil removal, treatments, and plantings

Treatments 1A (extensive soil removal) and 1B (minimal soil removal): no treatment, control zones

1A. In the extensive soil removal control zone there were no planted species found.

1B. In the minimal soil removal control zone no planted species were found.

Treatments 2A (extensive soil removal) and 2B (minimal soil removal): fertilizer, gypsum and plantings

2A. In the 2 x 2 plots the hydrology was such that all plots were dry in 1992. Comparisons of all planted species within the 2 x 2 plots showed *Pontederia* had the greatest percent cover and averaged 71% in the original 5 plots and 10% cover in one newly invaded plot (Table 3). *Eleocharis* averaged 44% cover in the original 5 planted plots. Additionally, *Eleocharis* invaded 7 more new plots and averaged 23% cover in these new plots. *Panicum* also averaged 44 % cover in the originally planted 5 plots and had invaded 3 new plots with an average of 10% cover. *Scirpus* was found in only 3 of the original 5 plots with an average of 38% cover. Averaged over the original 5 planted plots the % cover is 23 (Table 3). Additionally, *Scirpus* invaded one new plot with 10% cover.

In the 7, 3 x 10 plots *Eleocharis* sp. was in 1 plot and averaged 40% cover. *Panicum* and *Scirpus* also were in one plot each with 50 and 1% cover, respectively.

Table 1
Plant Density (#/m2) Response to Extensive Soil Treatments
Surviving Planted Species (2x2 plots)

	Treatments			
Species	**1A**	**2A**	**3A**	**4A**
Panicum	0.0	146.6 a ±46.5 A	55.1 a ±56.8 B	86.9 a ±42.4 B
Eleochris	0.0	42.9 b ±27.4 A	30.6 a ±21.0 A	59.1 b ±31.2 A
Pontederia	0.0	29.8 b ±17.3 A	24.0 a ±21.3 A	49.3 b ±38.2 A
Scirpus	0.0	1.1 b ±1.3 A	0.3 a ±0.4 A	0.7 c ±0.8 A

means followed by same cap. letter in rows or same lower case letter in columns are not sig. diff.

In the 7, 5 x 10 plots *Eleocharis* sp. occurred in one plot with 50% cover. *Panicum* occurred in one plot with 30 % cover. *Pontederia* and *Scirpus* were not found in the plots in which they had been planted.

In the 10 x 10 plots no planted species were found.

Panicum had the greatest densities of the planted species. *Eleocharis, Pontederia*, and *Scirpus* had lower densities in this treatment zone(see Column 2A in Table 1).

2B. In the 2 x 2 plots hydrology was such that moisture ranged from dry at the higher elevations to 3 cm water depth at the lakeside, lower elevations. *Pontederia* had the greatest % cover (48%) among all planted species within treatment 2B and invaded 2 new plots (5% cover) (Table 4). *Eleocharis* invaded the most new plots (5) and averaged 34% cover in the original 5 plots (Table 4) and 15% cover in the 5 new plots. *Panicum* averaged 15% cover in the original 5 plots and 1% cover in one newly invaded plot. *Scirpus* averaged 26% cover in the original 5 plots and 10% cover in one newly invaded plot.

In the 3 x 10 plots *Eleocharis* sp. occurred in one plot with 90% cover. *Panicum* and *Scirpus* each occurred in one plot with 30 and 40% cover, respectively.

Table 2
Plant Density (#/m2) Response to Minimal Soil Treatments
Surviving Planted Species (2x2 plots)

	Treatments			
Species	**1A**	**2A**	**3A**	**4A**
Panicum	0.0	36.9 a ±24.9 B	45.0 a ±35.8 B	134.9 a ±34.0 B
Eleochris	0.0	48.1 a ±21.9 A	54.6 a ±33.7 A	64.9 b ±24.8 A
Pontederia	0.0	20.8 b ±17.7 A	20.6 a ±20.0 A	24.9bc ±29.4 A
Scirpus	0.0	1.6 c ±0.7 A	1.0 c ±1.1 A	1.7 c ±1.6 A

means followed by same cap. letter in rows or same lower case letter in columns are not sig. diff.

In the 5 x 10 plots *Eleocharis* sp. occurred in one plot with 75% cover. *Panicum* and *Scirpus* each occurred in one plot with 35 and 50% cover, respectively.

In the 10 x 10 plots no planted species were found.

Among the planted species in this treatment, *Panicum* and *Eleocharis* had greater densities than *Pontederia.* *Scirpus* had the lowest densities (see Column 2B in Table 2).

Treatments 3A (extensive soil removal) and 3B (minimal soil removal): subsoiling, disking, fertilizer and gypsum

3A. In the 2 x 2 plots hydrology was such that all plots were dry. *Pontederia* averaged 42% cover in the original 5 plots (Table 3) and 11% cover in 3 newly invaded plots. *Panicum* averaged 16% cover in the original 5 plots and 3% cover in 2 new plots. *Eleocharis* only occurred in 3 of the original 5 plots and averaged 28% cover. *Scirpus* was not present in any of the original 5 plots but averaged 5% cover in 2 newly invaded plots.

In the 3 x 10 plots *Eleocharis* sp. occurred in one plot with 60 % cover. *Panicum* and *Scirpus* each occurred in one plot with 15 and 30 % cover, respectively.

In the 5 x 10 plots *Eleocharis* sp. occurred in one plot with 30 % cover.

Table 3
Percent Cover in Extensive Soil Removal Zones Planted Species (2x2 plots)

	Treatments			
Species	**2A (Low)**	**3A (Med)**	**4A (High)**	**1A (Control)**
Scirpus	**23 b** **±28** **A**	**0 b** **±0** **A**	**4.2 b** **±5.3** **A**	**0**
Panicum	44 ab ±29 AB	16 b ±18 B	51 a ±19 A	0
Eleochris	44 ab ±26 A	28 ab ±24 A	65 a ±41 A	0
Pontederia	71 a ±16 A	42 a ±13 B	39 a ±27 B	0

means followed by same cap. letter in rows or same lower case letter in columns are not sig. diff.
all means represent pct/cov in original 5 plots planted

In the 10 x 10 plots *Nymphaea odorata* occurred in 1 plot with 10% cover.

Within this treatment, there were no significant differences among the densities of the planted species (see Column 3A in Table 1).

3B. In the 2 x 2 plots hydrology was such that all plots were dry except for 3 of the 35 plots that were moist. *Eleocharis a*veraged 55% cover in the original 5 plots (Table 4) and 47% cover in 11 newly invaded plots. *Pontederia* averaged 40% cover in the original 5 plots and 10% cover in one new plot. *Panicum* averaged 12% cover in the original 5 plots and had not invaded any new plots. *Scirpus* occurred in only 3 of the original 5 plots with an average % cover of 38. *Scirpus* was also found in one new plot with 5% cover. The average over all 5 original planted plots was 23% (Table 4).

In the 3 x 10 plots *Eleocharis* sp. occurred in one plot with 60% cover. *Panicum* and *Scirpus* also occurred in one plot each with 40 and 25% cover, respectively.

In the 5 x 10 plots *Eleocharis* sp. occurred in one plot with 80% cover. *Panicum* and *Scirpus* also occurred in one plot each with 25 and 30% cover, respectively.

In the 10 x 10 plots no planted species were found.

Table 4
Percent Cover in Extensive Soil Removal Zones Planted Species (2x2 plots)

	Treatments			
Species	**2A (Low)**	**3A (Med)**	**4A (High)**	**1A (Control)**
Scirpus	**26 b ±21 A**	**23 b ±31 A**	**21 ab ±20 A**	**0**
Panicum	15 b ±9 B	12 b ±3 B	57 a ±20 A	0
Eleochris	34 ab ±19 A	55 a ±37 A	54 a ±21 A	0
Pontederia	49 a ±22 A	40 ab ±19 B	42 a ±41 B	0

means followed by same cap. letter in rows or same lower case letter in columns are not sig. diff.
all means represent pct/cov in original 5 plots planted

Within this treatment, *Panicum* and *Eleocharis* sp. had greater densities than *Pontederia*. *Scirpus* had the lowest densities (see Column 3B in Table 2).

Treatments 4A (extensive soil removal) and 4B (minimal soil removal): topsoiling, subsoiling, disking, fertilizer, and gypsum

4A. In the 2 x 2 plots hydrology was such that all plots were dry in 1992. *Eleocharis* occurred in only 4 of the original 5 plots with an average cover of 65%. (Table 3) *Eleocharis* also invaded 12 new plots and averaged 38% cover. *Panicum* averaged 51% cover in the original 5 plots and 1% cover in one new plot. *Pontederia* averaged 39% cover in the original 5 plots and did not invade any new plots. *Scirpus* only occurred in 3 of the original 5 plots and averaged 7% cover. Averaged over all 5 planted plots the % cover is 4.2% (Table 3).

In the 3 x 10 plots *Eleocharis* sp. occurred in one plot with 75% cover. *Panicum, Pontederia,* and *Scirpus* also occurred in one plot each with 30, 10 and 1% cover, respectively.

In the 5 x 10 plots *Eleocharis* sp. occurred in one plot with 85% cover. *Panicum* and *Scirpus* occurred in one plot each with 70 and 20% cover, respectively.

In the 10 x 10 plots *Nymphaea odorata* occurred in 2 plots averaging 17% cover.

Within this treatment, *Panicum* had the greatest density, followed by both *Eleocharis* and *Pontederia*. *Scirpus* had the lowest density (see column 4A in Table 1).

4B. In the 2 x 2 plots hydrology was such that all plots were dry in 1992. *Eleocharis* averaged 54% cover in the original 5 plots and 19% cover in 8 newly invaded plots. *Pontederia* occurred in only 4 of the 5 original plots with an average of 42% cover but had invaded 2 new plots with an average of 3% cover. *Panicum* averaged 57% in the original 5 plots with no new plots invaded. *Scirpus* only occurred in 4 of the original 5 plots with an average of 26% cover and had not invaded any new plots (Table 4).

In the 3 x 10 plots *Eleocharis* sp. occurred in one plot with 40% cover. *Panicum* and *Scirpus* also each were in one plot with 80 and 5% cover, respectively.

In the 5 x 10 plots *Eleocharis* sp. occurred in one plot with 70% cover. *Panicum* and *Scirpus* also occurred in one plot each with 95 and 5% cover, respectively.

In the 10 x 10 plots no planted species were found.

Within this treatment *Panicum* had the greatest density followed by *Eleocharis*, *Pontederia*, and then *Scirpus* (see Column 4B in Table 2).

Effect of treatments on densities and % cover of planted species within the extensive soil removal zones

Comparisons of densities of each planted species across the extensive soil removal treatments (1A, 2A, 3A, and 4A) indicated that *Panicum* was the only species that showed significant changes in densities (see *Panicum* row in Table 1). The greater *Panicum* density (146 plants per m^2) was found in the lowest treatment zone (2A) lower densities were measured in zones 3A and 4A (Figure 5).

Comparisons of % cover of each planted species across treatments indicated that *Pontederia* was significantly greater in the lowest treatment zone 71% (2A) (Table 3).

Effect of treatments on densities and % cover of planted species within minimal soil removal zones

Comparisons of densities of each planted species across all of the minimal soil removal treatments (1B, 2B, 3B, and 4B) showed that *Panicum* had the

most significant changes in density (Table 2). Greatest *Panicum* density was found in the treatment 4B zone followed by lower densities in treatments 2B and 3B (Table 2, Fig 5).

Comparisons of % cover of each planted species across treatments indicated that *Panicum* was significantly greater in the highest treatment zone (4B) with 57% cover (Table 4).

Nelumbo seeds and *Nymphaea odorata* were not successful, probably due a dryer hydrology from August, 1991 through January, 1993. (Figure 1).

Effect of each soil treatment on each planted species

Panicum. Density and % cover of *Panicum* in treatment 4B, receiving minimal soil removal, was greater than in treatment 3B or treatment 2B. This is logical because of the extent of mechanical and chemical treatments applied to treatment 4B. Less logical, is the great density of *Panicum* receiving extensive soil removal and the least treatment (treatment 2A). *Panicum* was also affected by high treatment, extensive soil removal (treatment 4A). It also averaged the greatest density increase (over 3000%) from the original number of plants planted among all the treatment zones and both extensive and minimal soil removal (Fig. 4).

***Eleocharis* sp**. There were no significant differences in densities or % cover among all the treatment zones including extensive and minimal soil removal (Tables 1 & 2, Fig. 5). *Eleocharis* did, however, invade the greatest number of new 2 x 2 plots. It averaged about 1,800 % increase in density among all treatment combinations (Fig. 4).

Pontederia. There were no significant differences in densities among all the treatment zones including extensive and minimal soil removal (Tables 1 & 2, Fig. 5). *Pontederia* did have greater % cover in treatment 2A than other treatments (Table 3). It averaged about 1,000% increase in density among all treatment combinations. (Fig. 4)

***Scirpus* sp**. There were no significant treatment effect on densities among all treatments, extensive or minimal combinations. *Scirpus* did decrease about 60% from the original planted density (Fig. 4).

Effect Of Treatments On % Cover Of Non-Planted Species Within Extensive Soil Removal Zones

Comparisons of % cover across treatments indicated that grasses had significantly greater % cover in the control zone and decreased with increased levels of treatment. *Typha*, however increased in % cover with increased levels of treatment. *Eleocharis acicularis* occurred only in the treated zones and did not change in % cover in response to increased treatments (Table 5).

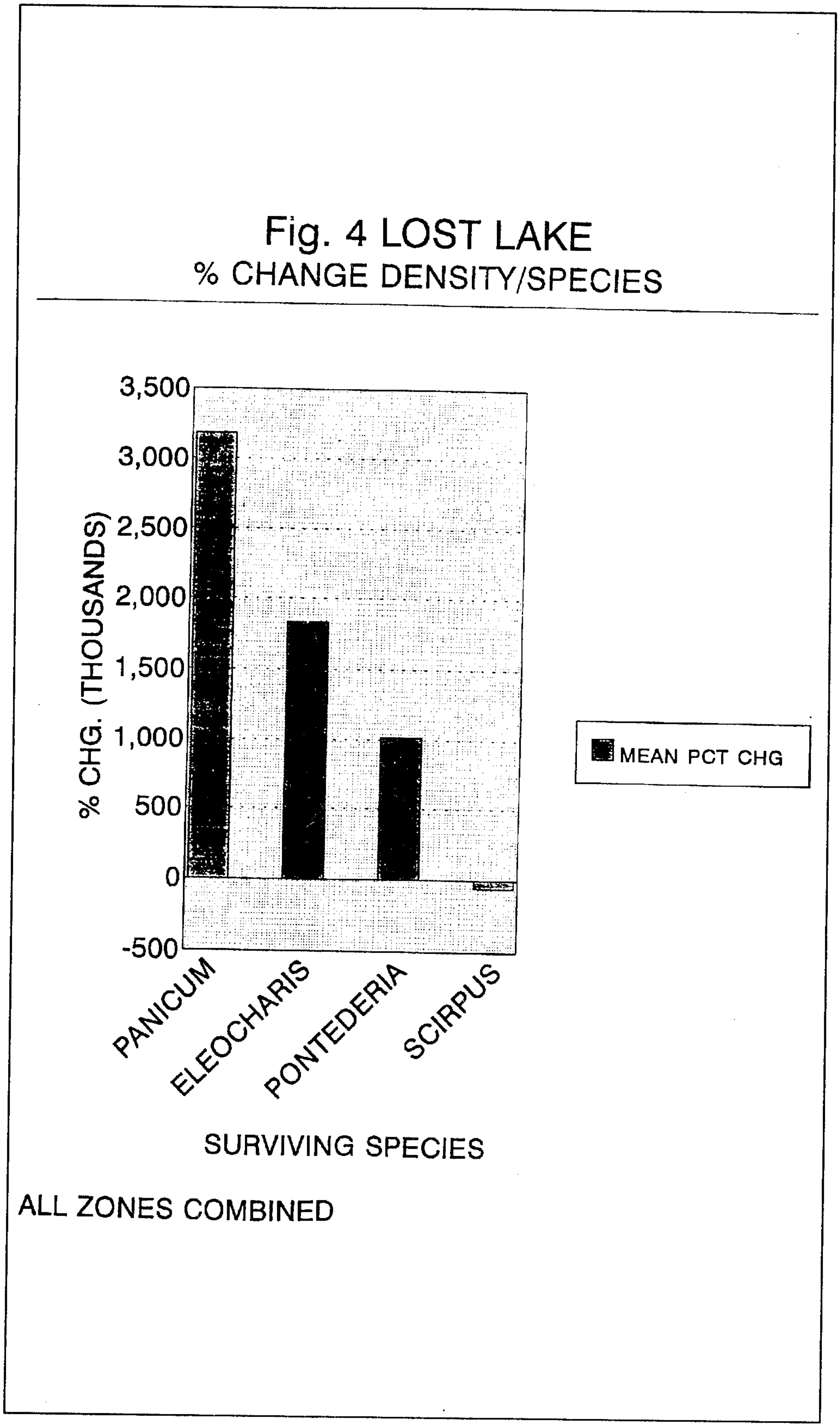


Fig. 4 LOST LAKE
% CHANGE DENSITY/SPECIES
% CHG. (THOUSANDS)
3,500
3,000
2,500
2,000
1,500
1,000
500
0
-500
PANICUM
ELEOCHARIS
PONTEDERIA
SCIRPUS
SURVIVING SPECIES
MEAN PCT CHG
ALL ZONES COMBINED

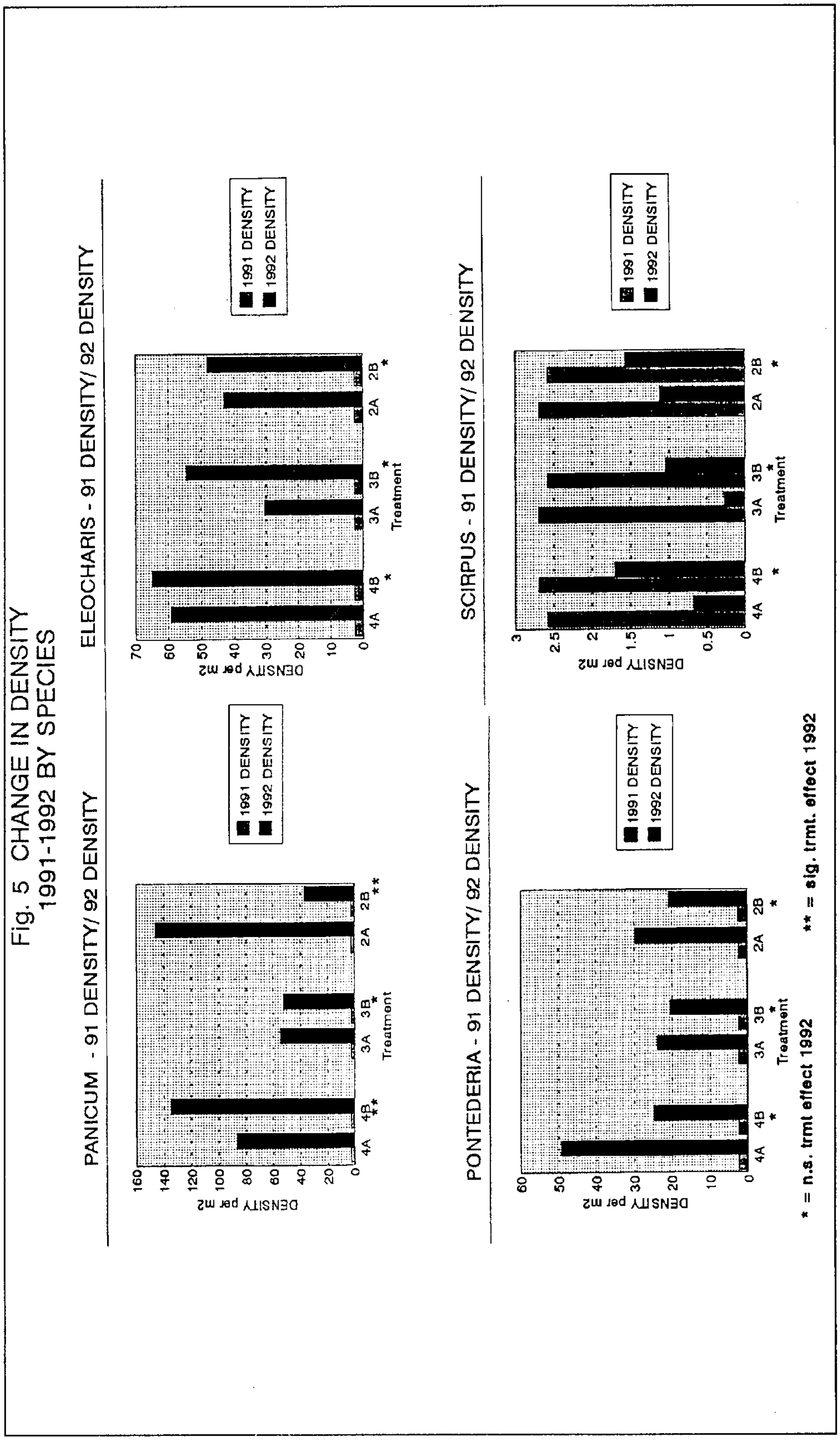


Fig. 5 CHANGE IN DENSITY
1991-1992 BY SPECIES

Table 5
Percent Cover Non-Planted Species All 2x2 plots PCT/COV Extensive Soil Removal

	Treatments			
Species	**1A (Control)**	**2A (Low)**	**3A (Med)**	**4A (High)**
Grasses	94 ±13 A	28 ±33 B	15 ±26 B	8 ±15 B
Typha	0.17 ±.86 C	8.9 ±19.5 B	22 ±19 AB	41 ±30 A
Eleocharis a.	0 ±0 B	6 ±15 A	4.4 ±7.6 A	8.8 ±12.7 A
means followed by same letter in rows are not significant				

Eupatorium was the only other non-planted species that consistently occurred in the control and treated zones, but at lower levels than grasses, *Typha*, and *Eleocharis acicularis* (data not shown).

Only one woody species occurred in the extensive soil removal zones. *Cephalanthus occidentalis* occurred in all but the high treatment zones and numbered 3 in the control, 45 in the low, 90 in the medium, and none in the high treatment zone.

Effect of treatments on % cover of non-planted species within minimal soil removal zones

Comparisons across treatments indicated that grasses had significantly greater % cover in the control zone and did not respond to treatments. *Typha* had lower % cover in the control zone and greater % cover in treatment zones. *Eleocharis acicularis* had only slightly greater % cover in the lowest treatment zone with no significant differences among the control and other levels of treatment (Table 6). *Polygonum* and *Eupatorium* both occurred in control and treated zones, but to lesser extents than grasses, *Typha*, and *Eleocharis acicularis* (data not shown).

Two woody species occurred in the minimal soil removal zones. (*Liquidambar styraciflua* and *Cephalanthus occidentalis*). *L. styraciflua* occurred in only the low and medium treatment zones and numbered 2 and 1, respectively. *C. occidentalis* occurred in all of the treatment zones. It numbered 47 in the control zone, 27 in the low treatment, 28 in the medium, and 27 in the high treatment zone.

Table 6
Percent Cover Non-Planted Species All 2x2 plots PCT/COV
Extensive Soil Removal

	Treatments			
Species	**1A (Control)**	**2A (Low)**	**3A (Med)**	**4A (High)**
Grasses	70 $\pm$27 A	1.43 $\pm$4.13 B	20 $\pm$28 B	30.5 $\pm$27 B
Typha	13.4 $\pm$18 A	32.6 $\pm$16.5 B	24 $\pm$26 AB	33 $\pm$24 B
Eleocharis a.	5 $\pm$7 B	23 $\pm$18 A	9 $\pm$10 B	2 $\pm$7.2 B

means followed by same letter in rows are not significant

Discussion

Of the planted species *Panicum hemitomon* was the most successful across treatments in terms of percent increase in density from the originally planted density. *Panicum* also had the greatest 1992 density across all treatment zones and across all planted species, with the exception of *Eleocharis* sp. having similar densities in some treatments (Tables 1 and 2). The robust above-ground, below-ground organs of this species permit aggressive vegetative reproduction, particularly during dry periods or periods of shallow, fluctuating water levels. Due to its stature and the density of stands, few species can become established beneath it (Kirkman, 1992). Since *Panicum hemitomon* relies primarily on vegetative reproduction, unless deep water inundation prevents stem emergence, as a result, re-establishment by seed is probably not critical to the success of this dominant grass, because it can probably survive somewhere along the hydrologic gradient in the bay.

Eleocharis sp. was the second most successful planted species and was not significantly affected by the treatments or by extensive vs. minimal soil removal prior to treatments.

Kirkman (1992) reports that disturbances such as soil tillage, have significant short term effects on community structure as well as on individual species responses. She further states that the effect of winter burning is primarily at the individual species level. Neither disturbance alters community dominance, although, soil tillage has a greater impact on cover of the vegetation than does burning. Our study indicated that only *Panicum* had a significant response to subsoiling, disking, topsoiling, and fertilizer and then only in the minimal soil removal zone. In the extensive removal zone, *Panicum* showed a significant density response to the no-till, fertilizer only treatment.

Of the non-planted species, *Typha* and grasses were about equally the most successful species. It has been reported that on highly disturbed soils that are revegetated, the dominance of grasses is promoted by applying high levels of nitrogen-containing fertilizers (Jordan, *et al.* 1987). While grass response to fertilization is dramatic, it appears to be short lived. In a study by Doerr and Redente (1983) grass reproduction was not significantly different than controls by the third year after fertilization. In our study, the grasses declined with increasing treatments and appeared to become better established in the extensive soil removal zones than in the minimal removal zones (although well established in both).

Aquatic plants have not become well established at Lost Lake. Kirkman (1992) points out that rare and aquatic species persist in the seed bank. Since Lost Lake's soil was removed and only certain areas received topsoil, it may be likely that the seed bank was severely depleted, however, *Typha* and grasses were very successful among the non-planted species found at Lost Lake. According to Harper (1977), seeds exist only in the upper 10 to 20 cm of soil. At Lost Lake, up to 12 inches (30.48 cm) were removed. Therefore, the lack of typical Carolina Bay aquatic vegetation could have been affected by this soil removal (and seed bank removal).

Woody species were relatively insignificant in density or percent cover. Only two species (*Cephalanthus* and *Liquidambar*) were found within the study zones. If monitoring efforts are sustained over a long term, woody species may become more significant.

Although Lost Lake's hydrology is similar to that of a typical Carolina Bay, it is noteworthy that revegetation strategies should accommodate the likelihood of drought conditions and include species that are tolerant or adapted to very dry conditions (and, of course, species that are tolerant of very wet conditions during the wet periods). Additionally, information on the nutrient content of the soil and of the water quality needs to be assessed to determine whether or not Lost Lake is similar to other Carolina Bays and can be expected to support the typical vegetation. For example, in April of 1992 *Nelumbo* (lotus) was replanted, but was not successful.

While restoring wetland ecosystems, consideration has to be given to what the intended goal of the restoration will be. According to Jordan, *et al.* (1987), imitation of a system is a more realistic endeavor than rote copying. Copying implies reproducing a system item for item, whereas imitating a system, implies creating a system that is not identical but rather, is similar in critical ways and therefore acts the same. Specifically, not just matching community to site, but actually being able to create the same type of community under various conditions. These created communities resemble other communities in various ways, but actually differ from them in species composition.

Testing ecological theories such as restoration or creation of wetlands such as Lost Lake requires answering basic fundamental questions, in determining whether or not the endeavor is truly a success. Sustainability, productivity,

nutrient retention and biotic reactions have to be considered when deciding if the restoration is successful (Jordan, *et al.*, 1987). Will Lost Lake sustain itself and eventually become a restored Carolina Bay? To answer this question we may consider what Zentner (1992) poses: that newly created landscapes will differ from mature ones just as children differ from their parents. The question is, Zentner continues, are the newly created systems changing in such a way that we can expect that they will approximate the model system within some time period?

We suggest that more important than the newly created system looking like the original system within some period of time is whether or not the newly created wetland system is sufficiently like the original one to be ecologically "fit," *i.e.*, the components being able to produce components that are themselves able to reproduce and sustain the whole system (sustainability). From this preliminary monitoring effort at Lost Lake it appears that the planted species *Panicum, Eleocharis,* and *Pontederia* have been successful in becoming established. Among the successful non-planted species are grasses, *Typha latifolia, Eleocharis acicularis, Polygonum* sp. and *Eupatorium* sp.

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Attachment

Vegetation Present in Plots at Lost Lake 1992

Cephalanthus ɔccidentalis
Cyperis sp
Eleocharis acicularis
Eleocharis quadrangulata
Eupatorium
Hydrocotyle umbellata
Liquidambar styraciflua
Ludwigia palustris
Nymphaea odorata
Panicum hemitomon
Plygonum sp
Pontederia cordata
Potamaogeton diversifolius
Scirpus cyperinis
Seteria sp
Typha latifolia

Constructed Wetlands for Sediment Control and Water Quality Improvements at Corps of Engineer Reservoirs, Charles W. Downer, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS

Abstract

The U.S. Army Corps of Engineers (USACE) is responsible for the stewardship and management of over 9 million acres of land associated with its water control projects. At many of these projects sedimentation and associated problems, such as resuspension of sediments, turbidity, and eutrophication, are a major concern. The Corps of Engineers has a limited ability to prevent non-point agricultural and urban runoff containing sediments and contaminants from entering its projects. However the Corps can effectively use its own lands for water treatment. One of the most cost effective and publicly supported methods is to construct wetlands on site, either in the fluctuation zone of the reservoir, or on the surrounding landscape. Several wetlands have been constructed and studied at Corps of Engineer projects as part of the Wetlands Research Program (WRP). Wetlands have been constructed in the fluctuation zone of Black Butte Lake, in northern California. Wetlands have also been constructed along major tributaries into Bowman Haley Lake, in North Dakota, and Ray Roberts Lake, in Texas. Construction techniques at each of these sites were simple and inexpensive. Proper siting of the wetlands played an important role in the low construction costs. Sedimentation and removal of non-point source pollutants are being studied at these sites as part of the Stewardship and Management Task Area of WRP. Preliminary results indicate that wetlands can be effectively used for sediment retention at USACE projects.

Introduction

Improving water quality is often one of the stated goals, or functions, of constructed wetlands. This is a common reason for construction, or a perceived benefit of many of the constructed wetlands at USACE projects. Often this can be an impetus for the construction of what is essentially a wildlife habitat project. Constructed wetlands may provide a low cost method of solving the very difficult problem of non-point source contaminants entering USACE reservoirs. Yet, to date, the use of wetlands to treat non-point source pollution has remained largely unstudied. In this paper constructed wetlands at three USACE projects will be examined. As is often the case, these projects were primarily constructed and operated to maximize wildlife usage, primarily waterfowl. Construction methods for these wetlands were generally inexpensive. Analysis of sedimentation and water quality have been conducted at these sites over the last year and are being continued. Preliminary findings of these investigations are presented.

Case Histories

As part of the Wetlands Research Program (WRP), three constructed wetland demonstration sites are being studied for their ability to remove sediments and other contaminants from inflows to USACE reservoirs.

Spring Creek Wetland, Bowman, North Dakota

The first project is a 24 acre constructed wetland along Spring Creek, one of three major tributaries into Bowman Haley Reservoir, located near Bowman North Dakota. Once a popular lake for recreation, Bowman Haley's popularity has suffered because of water quality problems in the lake. One of the purposes of the Spring Creek wetland is to treat storm water flows, which carry most of the contaminants.

The wetland was created in a natural depression near Spring Creek. A 1500 foot diversion channel connects the creek to the wetland, and becomes part of the wetland itself. A 50 foot weir is constructed across Spring Creek just downstream of the diversion channel. Flow into the wetland is controlled by a gated 18" corrugated metal pipe culvert. Outflows are controlled by a 48" drop structure. The elevation of the drop structure is the same as that of the top the diversion weir. The only source of surface water is that diverted from Spring Creek.

Water level meters are located near the upstream and downstream control structures. ISCO automatic water quality samplers are also located at both control structures. The samples are activated by water level and are used to sample storm events when flows are being diverted into the wetland. Samples are collected and analyzed for total suspended solids (TSS), total phosphorous (TP), total Kjeldahl nitrogen (TKN) and the herbicides, 2,4-D, atrazine, aldicarb, alachlor, carbofur, and cyanizen . A weather station, located at the wetland site, collects rainfall, evaporation, and other climatological parameters on an hourly basis.

Both feldspar sediment pads and plexiglass sediment disks are being used to measure sediment accretion in this wetland. Originally, two foot square feldspar pads were located at various locations in the wetland. This year, a grid of twenty-one sediment disks, 100 cm^2, were laid throughout the wetland to measure total accretion and spatial variations.

Ray Roberts Reservoir, Tioga, Texas

The second project is a 5.7 acre wetland located along Range Creek, a major tributary into Ray Roberts Lake, north of Denton, Texas. This wetland is one of 5 wetlands constructed along the creek. Water into this wetland comes from a variety of sources. Flows come from an upstream wetland/ storage area used primarily to control water in the downstream wetland. Flow

from the upstream wetland is controlled by a 30" round concrete pipe. Flood flows from this wetland are controlled by a 100' earthen spillway. At high creek water levels, flows spill in over the dikes; and at high lake levels, water spills in over the outlet spillway and comes through the outlet culvert. The wetland is located within the fluctuation zone of the reservoir and at very high lake levels the wetland becomes part of the lake. The wetland also has a very small drainage area.

Water level meters and ISCO automatic water samplers are located at both the upstream and downstream control structures. The samplers are water level actuated. Although bi-weekly samples are collected by hand, emphasis is on storm water sampling. Samples are collected and analyzed for TSS, TKN, TP, soluble reactive phosphorous (SRP), nitrate nitrogen NO_3, TN, conductivity, alkalinity, pH and the herbicide Atrazine.

Plexiglass disks are being used to measure sediment accretion in this wetland. Twenty seven disks are laid on a grid to measure total sediment accretion and spatial variations throughout the wetland.

Black Butte Lake, Orland, California

Two wetlands have been constructed in the fluctuation zone of Black Butte Lake in Northern California. The surface area of each of these two wetlands is approximately 5 acres. Wetland 1 is at elevation 460.5; wetland 2 is located at elevation 452.0. Normally the lake fluctuates between elevations 430 and 460. However, historically the lake has fluctuated between 400 and 480 feet. The wetlands have been submerged for a large portion of the study period, most of last spring and summer, and all of this spring and summer.

The wetlands were created by constructing dikes across areas that drain the lake bed during low water. Both dikes are approximately 550 feet in length and include a sandbag/concrete spillway 50 feet wide. Erosion control mesh material was placed along the dikes and the dikes were seeded with a mix of grasses.

Sedimentation is measured at the site using feldspar sediment pads and plexiglass sediment disks. There are 10 sediment pads and disks located in each wetland. When possible, grab samples for TSS are being collected after rain fall events.

Results and Analysis

Spring creek

Nearly four hundred samples from different storm events were collected and analyzed last year. The wetland showed good removal of TSS, with a removal efficiency of 72%, based on change in concentration. Mass treatment

efficiency was 98%, though much of this removal was simply due to reduction in flow. The concentration of the effluent was approximately 13 mg/L and seemed almost independent of influent concentrations. Wetlands produce a small quantity of TSS from organic material. Kadlec (1992) noted that in wetlands used for waste water treatment, effluent TSS was more a function of the wetland system than of the influent concentration, with the TSS in the effluent attributable to this organic source.

Treatment of nutrients and herbicides was much less effective. While mass treatment efficiencies were high (>90%), this is attributed to reductions in flow. Reviewing the data during periods where inflow was approximately equal to outflow showed a net reduction in TP of approximately 25%. There was little or no removal of TKN. Removal of TP is probably due to sedimentation of particulate matter. Surface wetlands typically cannot permanently remove phosphorous from the water column, though it may be temporarily stored in plant tissue. Removal of nitrogen in wetlands is believed to be accomplished by nitrification of ammonia and then denitrification. Nitrification occurs at the wetland bottom in the detritus layer. Because this wetland is newly constructed, it has not had an opportunity to build up this layer. It is expected that nitrogen removal will improve as the wetland matures.

Concentrations of herbicides were so low that calculating treatment efficiencies was not possible. Many of the 128 samples analyzed for herbicides had concentrations below detection limits. However, the percentage of samples with concentrations above detection limits, or hits, was reduced for four of the six herbicides analyzed. The highest concentrations were seen in the first storm event. No outflow occurred from this storm. These high concentrations were never seen at outflow during subsequent storm events. Outflow concentrations were approximately equal to inflow concentrations for following storm events. The detention time for these later storms was approximately 4 days, which is probably not long enough for significant treatment of herbicides. Also, this wetland lacks the thick vegetation and bottom detritus of mature wetlands. Herbicide treatment may increase as the wetland matures. Typical flows through the wetland are less than 1 cfs, which equates to a hydraulic loading of approximately 2.6 cm/d. This is in line with values for constructed wetlands used for waste water treatment reported by Watson et al. (1989) which ranged from 0.8 to 62 cm/d, and had a recommended value of 1.9 cm/d to treat primary waste water to secondary standards.

Ray Roberts

Two storm events have been sampled at Ray Roberts this spring. The storm events were large and flooding of the wetland occurred during the first storm event. Because of the large storm events, detention times have been short and treatment less than initially expected. Relative timing of peaks indicate that the detention time has been on the order of 8 hours for each of these storms. A time of travel study done with the upper wetland full and both

discharge gates opened, indicated a 5 hour 37 minute detention time, at an average discharge of 29 cfs.

The best removal has been for TSS. See Figure 1 for TSS concentrations during storm 2. As is shown in the figures, peak TSS numbers are substantially reduced (36%). During storm 1, no other constituents, TP, SRP, NO3, and atrazine, showed any significant reduction in concentration. During the second storm, SRP showed a 20% reduction in peak concentration and a 29% reduction in average concentration for the storm. None of the other constituents showed a significant reduction.

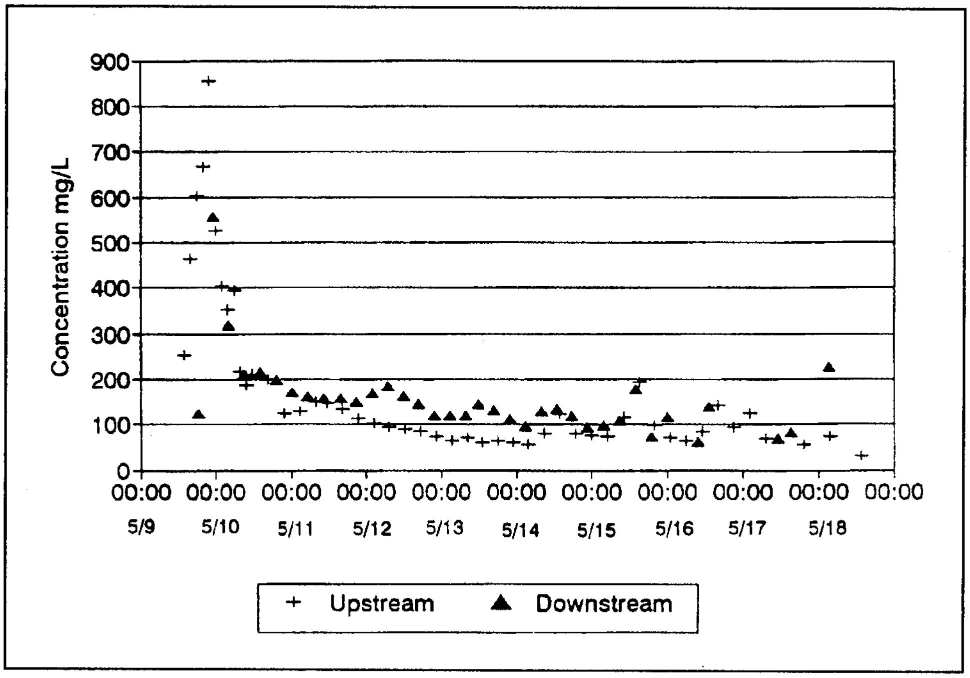

Figure 1. TSS Concentrations for Ray Roberts Wetland, Storm Event 2

Although this wetland is already fairly heavily vegetated it too is still in the development stage. However, the problem with treatment of water quality parameters seems to be a lack of detention time. Because of the small size of the wetland, compared to the flow, hydraulic loadings are high. For the time of travel study, mentioned above, the hydraulic loading was 308 cm/d. This is well above the recommended values listed previously.

Black Butte

Sediment accretion on the feldspar pads was measured in the field in October 1992 after the wetland areas completely dried out. In wetland 1, only 5 of the original 10 feldspar pads were located. Sediment accretion ranged from 9 to 36 mm and averaged 23 mm. For wetland 2, accretion ranged from 25 to 40 mm, and averaged 31 mm for the 8 pads located in the pond.

In addition, samples from each pad were dried and weighed to determine mass accretion. These samples were also analyzed for organic content. Mass accretion for wetland 1 was 24.00 kg/m^2. Mass accretion for wetland 2 was 39.5 kg/m^2. The volatile or organic portion of these samples was 9.2% for wetland 1 and 6.5% for wetland 2, or 2.24 kg/m^2 for wetland 1 and 2.56 kg/m^2 for wetland 2.

In relation to natural wetlands, a compilation of sediment accretion rates (Johnston, 1991) yielded a range of accretion rates of -0.6 to 26 mm per year and mass accumulations of 0 to 7.84 $kg/m_2/yr$. Thus, these wetlands are receiving and retaining a high amount of TSS compared to natural systems.

The wetlands receive sediment from a variety of sources. Each receives runoff, creek overflow and is seasonally inundated by the reservoir. Spot sampling of the wetlands during runoff events indicate that the ponds are retaining a large portion of the incoming sediments.

Wetland 2 had a higher rate of sediment accretion than wetland 1. The inflow samples did not indicate significantly higher runoff concentrations at wetland 2 as compared to wetland 1. It is possible that this increased sedimentation is due to sedimentation from lake inundation. Because of it's lower elevation it is inundated for a longer period of time. Additional sampling may help to determine the role of relative elevation in sedimentation in wetlands located in the fluctuation zone of reservoirs.

Conclusions

Wetlands at three USACE projects are being studied as part of the Stewardship and Management study area of the WRP. Analysis of the information to date, indicates that these wetlands function as effective sediment traps. Removal of other non-point source pollutants has been less effective. The immaturity of plant communities in these wetlands is probably a major factor. In addition, the wetlands at Ray Roberts Lake have insufficient detention time for typical storm events. Although longer, the detention time of the Spring Creek wetland is still probably inadequate for removal of herbicides.

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Is Big Better? Challenges And Opportunities in Large Site Wetland Mitigation, Steven A. Ott and Paul S. Evanoff, Johnson Johnson & Roy, Ann Arbor, Michigan

Introduction

Expansion of the Detroit Metropolitan Wayne County Airport in southeast lower Michigan will result in the loss of over 300 acres of wetlands. Based on the final Environmental Impact Statement (Federal Aeronautics Administration, 1990), plans for the restoration and/or creation of approximately 467 acres were required to be submitted for approval by the U.S. Environmental Protection Agency (EPA) and the Michigan Department of Natural Resources (MDNR) prior to any airport construction activities. The following paper describes the selection of the mitigation site, design and construction concepts and concludes with observations regarding opportunities and challenges associated with large site wetland mitigation programs.

Wetland Impacts at the Airfield

Losses of wetlands as a result of the airport expansion program necessitated the filling or draining of approximately 311 acres of wetlands. The losses by type are shown in Table 1:

Site Selection

Selection of a credible site for wetland mitigation was essential to gaining project approval from the regulatory agencies. Important considerations in this phase of the project were the location, physical constraints to site development and timeliness of acquisition of property for the proposed mitigation site. In the initial stages of negotiations the resource agencies specified criteria for determining an acceptable location:

- locate in Wayne County
- select no more than three sites
- utilize agriculturally converted wetlands to the extent possible
- minimize displacements of homes/businesses

Several sites were subsequently located in southern and western Wayne County in the few rural townships within Wayne County which generally satisfied these criteria. One important consideration - location within the same watershed - was not achieved due to the location of the Airport in the sub-basin which also encompassed the Detroit Metropolitan area. Limits were also imposed by the Federal Aeronautics Administration (FAA) regarding

Table 1
Wetlands Affected by the Airport Project

Project	FO	EM	SS	D	OW	Total
	Grading and/or Filling					
Crosswind Runway & 3L Extension	51	22	11	4	0	88
South Access Road	6	0	1	1	0	8
4th Parallel Runway	19	4	20	4	0	47
South Terminal	21	4	5	3	1	34
Air Cargo/Terminal Support	34	14	6	4	0	58
West Side Development	52	1	14	5	0	72
Other	1	0	3	0	0	4
TOTAL (AC)	**184**	**45**	**60**	**21**	**1**	**311**

Wetland Types: Forested (FO), Emergent (EM), Scrub/Shrub (SS), Drain (D), Open Water (OW)

minimum setback distances from the Detroit Metropolitan Airport or any other commercial airport facilities (Order 5200.5A). A minimum 10,000-foot radius was specified within which no wetland mitigation site could be located, while FAA would also require a review of any site within 5-miles of the airport. With input from local community representatives, a single site was finally selected in Sumpter Township. The support and cooperation of the local officials during the ensuing site investigation and land acquisition was instrumental to the project's success.

The selected site consisted of approximately 900 acres in Sections 25, 26 and 35 of Sumpter Township. The site was predominantly agricultural in use with dispersed woodlots and fencerows. Relief was more pronounced in the western and northern portions of the site, where sand dunes in excess of 10 feet in height were apparent. The remainder of the site was flat with most grades less than two percent. For wetland mitigation the site's strongest assets were the predominance of channelized drains - including the Disbrow, Lords, Botson, Mosquito, Clark-Morey and Batway - which crossed through the site in a southerly and easterly direction. The flat relief, predominance of agricultural lands, hydric soils, and county drains distinguished this site as having excellent potential for wetland mitigation.

Acquisition of the site in a timely manner was an important factor since the Sumpter site (and all other sites considered) were in private ownership. The proposed mitigation site consisted of 74 parcels occupying over 900 acres; in addition, the project also required the displacement of 20 residences. All negotiations were conducted according to the Federal Uniform Relocation Act, although 3 parcels were acquired by condemnation.

Site Planning and Design

Development of the mitigation site was approached with the objective of utilizing the best features and opportunities of the site as compensation for the loss of specific types of wetlands at the airfield. The general design concept developed for this project involved impounding the site's primary watercourse, the Disbrow Drain, with a low-head earthen dam and concrete overflow structure, thereby creating a higher water elevation with varying depths and wetland types behind it. Important natural features to remain included existing woodlots, wetlands, state threatened and endangered plant species and uplands where wetland creation was impractical and costly. These resources also enhanced the site's diversity.

Field investigations were undertaken to satisfy federal and state regulatory requirements. Due to FAA involvement, studies were made for: 1) existing wetlands (including farmed wetlands), 2) threatened and endangered species, 3) archeological resources, 4) areas of environmental contamination and 5) historic sites. The site's configuration also required that other drains on-site, including the Clark-Morey, Lords and Batway, be rerouted around the perimeter of the site due to degraded water quality and extremely flat gradient, which would have flooded upstream riparian land owners.

As a result of these investigations, a master site development plan was developed along with a detailed mitigation and long-term management plan. The plans called for the following wetlands to be restored, maintained and protected in perpetuity at the Sumpter Township site.

Table 2
Proposed Wetland Mitigation

Wetland Type	Area (Acres)	Percent
Forested Wetland	179	38
Emergent Wetland	127	27
Wet Meadow	97	21
Shallow Water Wetland	31	7
Deep Water Wetland	27	6
Deep Water Aquatic Habitat[1]	6	1
TOTAL WETLAND MITIGATION AREA	**467**	**100**

[1] Depth greater than two meters not credited as compensatory mitigation.

Quantities identified above represent in-kind replacement at a ratio of 1.5 to 1.0.

Once the initial wetland mitigation plans were prepared, the documents were submitted to the MDNR and the EPA and other federal, state and local

agencies for initial approval. Subsequent to acceptance of these documents, JJR undertook preparation of construction drawings and specifications to implement the proposed design. Bid documents were prepared in three packages: 1) demolition, 2) earthwork and 3) revegetation.

Issues

Earthwork. Several issues emerged during the course of the contract document preparation. One of the most difficult issues to resolve pertained to spoil disposal. Due to property constraints, little area was available to Wayne County for the disposal of excess spoil material from the excavation. It was estimated that slightly under one million cubic yards would be excavated, resulting in the need to dispose of approximately 600,000 cubic yards of material off-site. The nearby location of a new landfill provided an excellent opportunity for using this spoil as daily cover and capping, while minimizing material hauling costs. Other disposal sites in the Township were screened to insure avoidance of wetlands and floodplains.

Soil separation by type was incorporated into the earthwork plan and can allow for various combinations and experimentations in wetland planting schemes. A workable earthwork management plan was essential to meeting the time constraints imposed by the permit conditions and seeding schedule. The planning of individual work tasks, coordinating the movement of equipment and personnel, and providing for weather contingency plans were among the more obvious components required for timely completion of a project of this magnitude and complexity. During construction, it soon became apparent that constructing the wetlands in smaller parcels of work could allow for some continuance of work in the event of inclement weather.

A third critical issue in implementing this phase of the project was the importance of accurate field engineering. Precision in executing the earthwork phase through setting low tolerances for finish grades - within 0.1 foot - is essential. The entire site was surveyed on a 50 foot grid to verify compliance with specified grades.

Revegetation. A second major element in the construction program involved establishment of wetland vegetation appropriate to the various wetland types. Various techniques were developed for the revegetation program including: 1) seeding with the use of a range drill, 2) planting of tubers and emergent plants, 3) planting of bare-root seedlings and whips, and 4) revegetation by natural succession. In order to avoid problems in implementing this phase of the work several strategies emerged:

1. Providing sufficient quantities of seed from the appropriate hardiness zone; this project required a minimum of two growing seasons to collect the specified quantities of seed;

2. Determining the amount of plant material stock which is commercially available; the project required securing plant stock over 1 year in advance. Contract growing for some species was required;

3. Allowing sufficient time between contract award and installation to provide for items 1 and 2 above;

4. Qualifying the seed supplier and confirming credentials of all subcontractors on the project, particularly if the revegetation phase is made part of the earthwork contract (include seed suppliers, seed collectors, nursery personnel, seeding contractor, and landscape contractor).

Opportunities and Challenges

Large site wetland mitigation - at the scale being undertaken for the Detroit Metropolitan Wayne County Airport - represents unique opportunities in permitting, design and implementation. Construction of wetlands in excess of 400-acres and the acquisition of nearly 900 acres of property offers any project sponsor certain advantages and disadvantages.

Advantages. Distinct advantages are evident in large site mitigation particularly in the early stages of the project, when securing regulatory and permitting approvals. With the selection of a site, a single master plan for mitigation design can be approved, providing a long term plan for phased construction. From an ecological point of view there are considerable benefits to large sites where the size of individual wetlands can improve habitat diversity, through the presence of a greater number of types of wetlands. The advantages are most evident for waterfowl and large mammals since substantial expanses of habitat can be provided within the site.

One final opportunity which larger sites may offer pertains to the public use of the property. Sites, such as the one in Sumpter Township, can provide important recreational, interpretive, and educational opportunities, not otherwise available to local residents. The goal is to utilize not just uplands, but wetlands, as the focus for the placement of recreational amenities; examples include: hiking, equestrian, and canoe trails, educational displays, aquatic botanical gardens, fishing and picnicking.

Disadvantages. There are considerable obstacles which must be overcome in initiating large site wetland mitigation projects. One of the more critical issues pertains to gaining support from the host community or the local jurisdiction(s) most directly effected. Typically questions of location, necessity of the project and the displacement of residents, farms or businesses require clear and direct responses. The support of the host community can be of particular benefit when conducting public information meetings, or in discussions with effected land-owners. Loss of existing tax base and future long-term revenues typically arise in discussions with local officials. These losses can often be offset through provision of other benefits to the local community, such as road

improvements, stormwater management, recreational facilities, or other infrastructure improvements.

Another key disadvantage in large site mitigation pertains to the matter of funding. Adequate funds must be available to acquire property, conduct site investigations, secure permit approvals, and construct the wetlands. These tasks require considerable revenues with much of the funding required in advance of the actual project implementation. Where costs of wetland construction have ranged from $30-50,000 per acre, the capital cost of undertaking any large site wetland mitigation project can be imposing. Bond monies in the amount of $12 million were allocated for the Detroit Metropolitan Airport wetland mitigation project.

Contractor qualifications must also be carefully addressed during the bidding process to ensure that the project will be constructed according to the plans and specifications prepared. In particular the contractor's experience in large earthwork projects, the contractor's demonstrated ability to plan and manage a project of such magnitude and complexity, and the availability of personnel and equipment must be confirmed during the contractor qualification phase, or in advance of award. Where the owner specifies a single general contractor, similar qualifications must also be sought out for the landscaping and seed suppliers which will likely participate on the project.

Summary

Wetland mitigation requires considerable knowledge, and planning to be successful. Consideration of large site wetland mitigation only magnifies these needs, placing even more importance on the planning and pre-construction phases of the project. While such projects may occur less frequently and with greater impacts to individual property owners or the local community, there are nevertheless considerable opportunities and advantages to larger scale wetland mitigation projects. In the spectrum of wetland mitigation there is a role for large site restoration which can create positive and environmentally sound benefits.

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Appropriate Technology for Wetlands Hydrologic Design, Lisa C. Roig, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS

Abstract

Adequate hydrologic analysis is fundamental for designing successful wetland restoration projects. A variety of techniques are available to describe surface water flow in wetland watersheds. Statistically based hydrologic analysis procedures project extreme flow conditions. Hydrologic simulation techniques are then used to route flood waves, to describe currents, and to compute transport. Simulation models range in complexity from lumped parameter models, such as the unit hydrograph, to distributed parameter, numerical hydrodynamic models. The following project attributes should be considered when selecting a hydrologic analysis tool:

a. type of control structure or construction feature to be designed.

b. wetland type.

c. availability and extent of hydrogeomorphic data.

d. restoration project objectives.

e. project cost.

In this study, classical hydrologic techniques are applied to problems of wetland restoration design and management. Design features considered include design of culverts, gates, channels, and levees. The techniques considered include frequency analyses, the rational method, the unit hydrograph, the Muskingum method, and open channel flow models. Appropriate use of these methods to achieve specific design objectives is discussed.

Introduction

Wetland restoration and management projects often require the design of control structures. Hydraulic structures used in wetland operation and management include culverts, gates, and weirs. Project design can include surface grading, channel construction, and levee construction. The design criteria for wetland engineering features includes traditional engineering objectives such as flood control, but also encompasses non-traditional objectives such as promotion of beneficial wetland plant and wildlife species. Engineers work with biologists and ecologists to determine appropriate design conditions, then apply principals of hydrology and flood plain analysis to ensure successful design and operation of the hydraulic structures.

The tools available to study wetland hydrology and hydraulics range in complexity from "back of the envelope" calculations to numerical hydrodynamic models. The appropriate analysis tool for a specific design problem will depend upon the type of structure or construction feature to be designed, the wetland site, the availability and extent of hydrogeomorphic data, the project objectives, and the cost of the project. In this paper, selection of appropriate hydrologic analysis tools is discussed.

Hydrologic Analysis Tools

Hydrologic analysis tools are available to address a variety of issues. The issues of interest for wetland hydraulic design include the following:

a. design storm, or design tide

b. peak flow

c. detention capacity

d. hydrodynamic circulation.

Design Storms and Design Tides

The design storm is the maximum storm event that an engineering feature can accommodate without failure. In wetland restoration, the discharge resulting from a design storm is used to determine the basin storage capacity, the minimum culvert dimensions, or the minimum channel conveyance. Similarly, a design tide is the tide with the maximum water surface elevation that can be accommodated by the engineering project. The design storm and the design tide can be determined by means of frequency analyses.

Frequency analyses use historic time series of measured rainfall, runoff, or tide height. The design event is chosen as the event having a probability of recurrence that is less than the threshold of risk prescribed by project objectives. Methods of computing the probability density function for hydrologic time series are treated extensively in the literature. A comprehensive treatment of the subject is provided by Bedient and Huber (1992).

The peak discharge resulting from a design storm is a useful piece of information for the design of a culvert or gate. If the watershed is gauged upstream of the wetland restoration site, the time series of discharge can be used to determine the peak flow. Wetland restoration sites are rarely situated on conveniently gauged streams. Instead, local depressions, flood plains and side channels are used for wetland restoration projects. These small watersheds derive inflow from local drainage and urban runoff, which may be supplemented by freshwater diversions. The peak flow in an engaged watershed must be determined by rainfall-runoff computations, described in the next

section. The design storm is determined from frequency analysis of the historic rainfall time series taken from a local rain gauge.

Inlets to tidal wetlands are rarely gauged. The tidal data from a nearby harbor or marina can be used where tidal elevation time series are not available. Frequency analyses are used to determine the probability of recurrence of an extreme high tide event. The peak tide height from the design tide will determine the height of levees and islands in the restoration project.

Whether designing for a freshwater wetland or a tidal wetland, the analysis of historical hydrologic time series data is critical to the success of a wetland design project. The design discharge and the design water surface elevation must be carefully selected to ensure protection of adjacent developments, to prevent channel scour, and to protect habitat with a high degree of reliability. Where the historic record is insufficient, a monitoring program should be initiated. At a minimum, an annual rainfall record is required for proper hydrologic design. A thorough analysis of the historic record ensures that the proposed engineering measures will perform properly under extreme conditions.

Peak Flows

As stated in the previous section, wetland restoration sites are rarely situated in gauged watersheds. The peak flow in the wetland watershed can be computed using rainfall-runoff analysis. Culverts, gates, and weirs in the restoration project are designed to accommodate the peak flow of a design storm so that water levels upstream of the structure will not exceed basin capacity. Certain wetland plant and wildlife species can be adversely impacted by excessive flooding. Rodents, for example, seek refuge from floods by fleeing to higher ground. If water levels are allowed to inundate interior islands, rodents can become trapped or drowned. Design of control structures to accommodate peak flows ensures that suitable water levels are maintained during floods.

Rational Method

The simplest rainfall-runoff method is the rational method. The rational method can be stated as

$$Q_{peak} = \Sigma_{j=1,n}\ C_j\ i\ A_j$$

where

Q_{peak} = peak discharge at the outlet (L^3/T).

j = index of catchment sub-regions.

n = number of catchment sub-regions upstream of the outlet.

C_j = runoff coefficient corresponding to the predominant land use or vegetation type in subregion j.

i = rainfall intensity (L/T).

A_j = surface area of sub-region j (L^2).

The assumptions of the rational method are as follows: 1) rain falls at a uniform intensity over the catchment area; 2) the duration of rainfall is sufficient that the entire catchment area contributes to the discharge at the outlet (equilibrium hydrograph); and 3) storage and infiltration losses are proportional to the rainfall intensity, and are independent of antecedent precipitation. The rational method is often used in engineering design because the peak discharge computed by this method is the equilibrium discharge, and is therefore greater than the discharge expected from an actual storm of limited duration.

In wetland hydraulic design, the specification of runoff coefficients is particularly important. The runoff coefficient accounts for depression storage, infiltration, and evapotranspiration of rainfall. If the wetland is completely submerged during a storm event then depression storage and infiltration can be ignored. The peak discharge for engineering design purposes will occur when all depression storage is filled and the soil is completely saturated. All excess precipitation will then be directed to the outlet as direct runoff. Therefore, the runoff coefficient for a submerged wetland is essentially 1.0 since evaporation from the water surface usually can be neglected during a storm event.

If the wetland catchment area or sub-region is not completely submerged, then the runoff coefficient is estimated according to soil type, vegetation type, and depression capacity. Values of the runoff coefficient quoted in the literature for vegetated areas range from 0.05 to 0.35. Values of C are lower for sandy soils and higher for dense soils. The slope of the sub-region also affects the value of C. Steeper slopes result in higher values of the runoff coefficient than mild slopes. Finally, the vegetation density affects the runoff coefficient. Higher plant densities reduce runoff and increase evapotranspiration, resulting in a lower runoff coefficient than for sparse vegetation.

The rational method has been used extensively in small urban watersheds where runoff coefficients for impervious materials are well known. The method is less reliable in vegetated watersheds because of the uncertainties associated with the runoff coefficient. For design of wetland hydraulic structures, the rational method is most useful for sub-

merged wetlands with small catchment areas (less than 10 acres). The uncertainty in assigning appropriate values for the runoff coefficient increases with increasing catchment area. The assumption of an equilibrium hydrograph is reasonable for small watersheds but is rarely achieved in larger basins where the time of concentration is large.

Unit Hydrograph

In wetlands with large catchment areas, the unit hydrograph may be used to estimate peak discharge for a storm of a given duration. This method permits the engineer to design for a realistic storm of limited duration, unlike the rational method which assumes that the storm duration is equal to or greater than the time of concentration. The assumptions of the unit hydrograph method areas follows: 1) the watershed response is linearly related to rainfall intensity; 2) the rainfall during a storm is spatially and temporally uniform; and 3) the watershed response is independent of antecedent precipitation. The assumption of linearity is adequate to determine design discharges for culverts and gates. These assumptions are not appropriate for design of wetland channels and habitat areas.

The unit hydrograph for a storm of a given duration can be derived by monitoring the discharge at the outlet during a single storm event. The time-discharge response recorded for a two-hour rainfall event is assumed to have a characteristic shape which is constant for all two-hour storms. The magnitude of the discharge is assumed to be linearly proportional to the rainfall intensity. Therefore, the unit hydrograph represents the basin outflow (in cubic inches per second) resulting from one inch of direct runoff generated uniformly over the drainage area at a uniform rainfall rate during a specified period of rainfall duration (Sherman, 1932). This method is advantageous when little historic data is available. The response of the watershed to a design storm can be estimated from storm hydrographs measured at the outlet over a short monitoring period (approximately one year). However, the assumption of linearity is not realistic, particularly when extended to extreme flow events. The uncertainty associated with estimates derived by the unit hydrograph method is high.

Hydraulic Flood Routing

Non-linear methods of hydraulic routing within the wetland watershed are useful for determining peak discharge, for predicting the temporal response of the wetland to a flood event, and for analyzing spatially and temporally heterogeneous hydrologic events. Hydraulic

routing utilizes physically based equations of open channel flow to account for channel resistance and storage capacity. The degree of accuracy for these methods is high provided that the appropriate forms of the equations are applied, and the hydrogeomorphic data supplied to the model is accurate. The data required for hydraulic routing includes

a. temporal and spatial distribution of rainfall for the design storm.

b. spatially distributed runoff coefficients, or inflow storm hydrographs for each of the catchment sub-regions.

c. channel and flood plain cross-sections over the basin.

d. channel roughness characterization.

e. downstream boundary condition.

Data required for hydraulic routing must be generated as part of the wetland design project. Recent developments in computer software have made processing and analyzing geomorphic data much easier than in the past. Geographical information systems (GIS) and graphical data displays provide special purpose tools that are ideally suited to watershed analysis. A software package called GEOSHED has been developed to analyze hydrologic characteristics of catchment basins (Richards, 1993b).

The effort required to perform hydraulic routing can result in a net cost savings over designs based on the rational method or the unit hydrograph, in spite of the greater amount of data required. A large degree of uncertainty is associated with both the rational method and the unit hydrograph method. This uncertainty can result in overestimation of the design discharge and the need to specify a high factor of safety. A project that is over-designed for the site will have concomitant excess material and construction costs. Design phase site evaluation and data collection is a cost effective approach because time charged in pre-construction analysis is typically cheaper than time charged during construction.

Hydraulic routing models are sufficiently complex that a computer program is employed to perform the calculations. Computer models also permit the engineer to specify more spatial heterogeneity in the catchment sub-regions than can be considered using hand calculations. Thus, the physical characteristics of the wetland watershed can be accurately represented, which reduces uncertainty in the calculated peak flows. Hydraulic routing models represent drainage of the catchment

area as flow through a network of one-dimensional conveyance channels.

The simplest routing methods, such as the Muskingum Method, are based on continuity of mass. Travel time through a reach is estimated from the channel storage capacity. In practice, the travel time coefficients for Muskingum routing are back-calculated from observed storm hydrographs. Models based on physical characteristics of the watershed are preferred for wetland restoration projects because measured hydrographs are rarely available. Hydraulic routing can be calculated by simultaneous solution of the equations of momentum conservation and mass conservation. Examples of physically based routing models are the diffusive wave model, the kinematic wave model, and the dynamic wave model (Henderson, 1966). Many public domain computer programs exist to facilitate hydraulic routing calculations, including the model HEC-1 (Hydrologic Engineering Center, 1981). The GEOSHED software package integrates a GIS data base with HEC-1 to perform hydraulic routing calculations in spatially heterogeneous watersheds (Jones, et al. 1990; Nelson, et al., 1993; Richards, 1993b).

A friction coefficient must be specified for solution of the momentum equation in open channel flow. This coefficient describes the resistance force caused by the bed and the vegetation. Mannings and Chezy coefficients are widely used. In wetland watersheds, resistance due to vegetation is high, and the effect of the vegetation on the flow can extend throughout the water column. Mannings n values from 0.1 to 0.35 have been reported for hydraulic routing in wetlands, with higher values corresponding to greater vegetation densities. Recent research indicates that Mannings n values in vegetated channels are not constant, but vary with flow velocity and depth. (Roig, 1993).

The methods discussed herein for computing the peak discharge in an engaged watershed include the rational method, the unit hydrograph, and hydraulic routing. Of these methods, hydraulic routing provides the highest degree of accuracy and reliability. The rational method is adequate for small wetlands that are largely inundated during the design storm, and where over-design of the structure will not result in excessive construction costs. Collection of geomorphic data for hydraulic routing can be a worthwhile investment because peak flows are more accurately estimated. A more efficient design for the control structure will result.

Detention Capacity

Wetland restoration projects provide multiple beneficial uses. Project benefits include recreation, wildlife habitat, water quality enhancement, and flood control. Flood control benefits result when a basin is allowed to remain largely undeveloped. The potential for damage of real property due to flooding is minimized, and the basin is available for recreation and/or wildlife habitat during non-flood periods. The detention capacity of the wetland watershed is used to determine flood attenuation potential.

Detention capacity is a function of the basin morphology and the outlet geometry. Storage volume in the basin can be computed by means of topographic maps, by manipulation of GIS data, and from wetted area curves. The hydrograph at the outlet for a design storm is determined by means of hydraulic routing calculations. The outlet may be a channel, a culvert, a gate, or a weir. Design criteria for the outlet structure may include controlled release of detained water to prevent flooding of downstream developments.

Hydrodynamic Circulation

Wetland engineering requires that hydraulic control structures and construction features produce a pattern of inundation that promotes the growth of beneficial wetland species. The frequency, duration and depth of inundation events have a combined effect on plant species distribution. Certain aquatic animal species exist in narrow ranges of hydraulic conditions that are related to the maximum current velocity, the minimum current velocity, the degree of vertical mixing, the salinity, and the stability of the channel substrate. A two-dimensional, vertically averaged hydrodynamic model can be used to predict circulation and ensure that hydrodynamic conditions meet biological requirements. Parameters such as channel dimensions, gate operation schedules, and weir heights can be adjusted within the model to test the design against biological design criteria (Richards, 1993a). Example applications of a two-dimensional hydrodynamic model are presented by Evans and Roig (1993).

Acknowledgements

The information presented herein, unless otherwise noted, was obtained from research conducted under the Wetlands Research Program of the United States Army Corps of Engineers by the Waterways

Experiment Station. Permission was granted by the Chief of Engineers to publish this information.

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Design and Construction of a Coastal Plain Small Stream Swamp in Eastern North Carolina, Jeff Furness[1] and Ted Shear[2]

Introduction

In 1981, a dike was built around 1500 acres in Beaufort County, North Carolina, to contain waste clays from phosphate mining. The area was never used for clay disposal. Ownership passed to Texasgulf Inc., a major producer of phosphate products, which decided to use the area for research and demonstration of restoring and creating forested wetlands. Plans were developed to restore one swamp and to create a new swamp from degraded uplands. Construction was completed in March 1992.

Description of the Degraded Site

The dike intersected Brown Run and Crawford Mill Run streams, tributaries of Durham Creek, which drains into the Pamlico River (Figure 1). They are classified as Coastal Plain Small Stream Swamps (Schafale and Weakley 1990), typically called "branch bottom" creeks - intermittently flooded, broad, flat creeks with fairly steep channel banks. These creeks flood after rains and water levels slowly recede over the following days. They are wetter in the winter with heavier rainfall and lower evapotranspiration and drier during summer. Before disturbance, Brown Run and Crawford Mill Run supported a variety of bottomland hardwood species. The dike restricted the flow of the creeks, resulting in permanent flooding upstream. The hardwood species do not tolerate permanent flooding. Within a short time, all of the trees died and the creeks no longer functioned as branch bottomlands.

The dike was constructed from subsurface clays borrowed from adjacent upland and wetland areas. Topsoil was pushed aside and 3-5 ft of subsurface clays were removed. The exposed subsoil was extremely infertile and compacted. Ten years later, these sites remained essentially unvegetated.

Restoration of Crawford Mill Run

Restoring Crawford Mill Run could be easily accomplished by removing the dike to restore flow. The dike intersects the broad stream at an oblique angle, with over 300 linear ft of dike in the basin. It was determined that removing all of the fill from the stream was prohibitively expensive. Instead, a channel through the dike was designed to pass flow from the 25 year storm unimpeded. The channel needed to be lined to prevent scouring and erosion,

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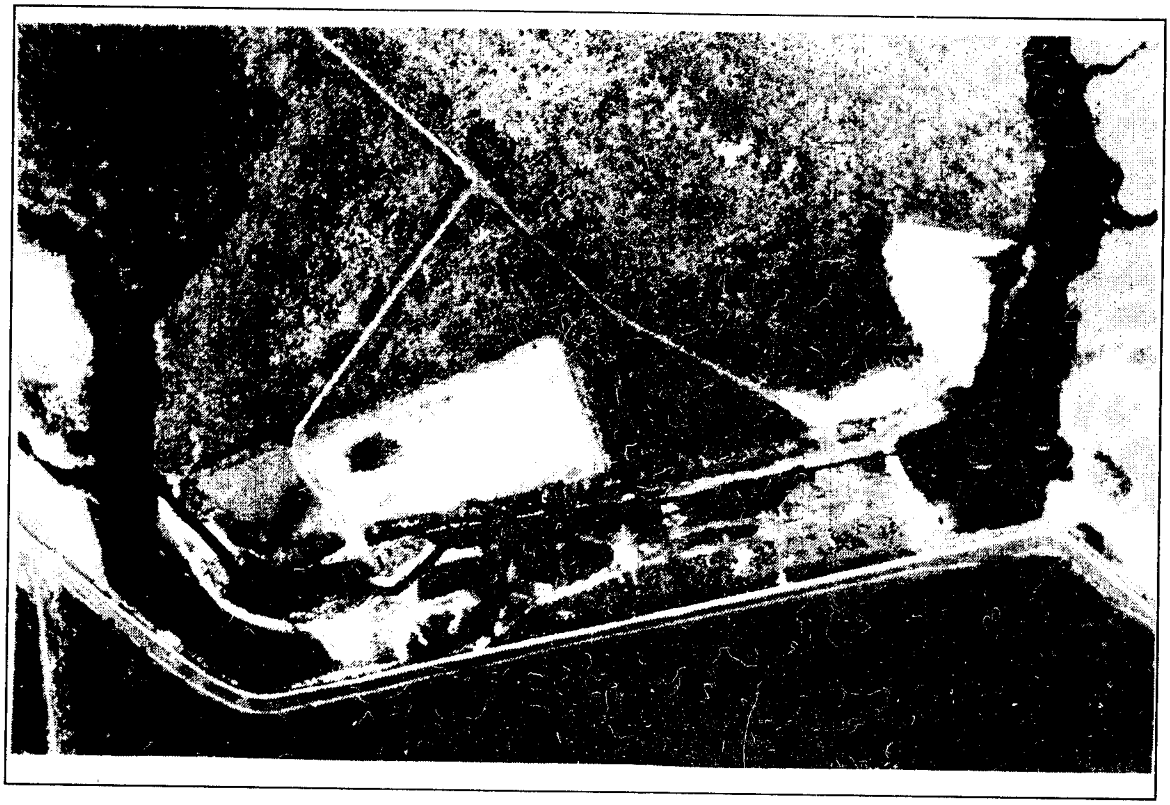

Figure 1. Aerial view of diked area. The dike runs across the bottom third of the picture. Impounded streams are Crawford Mill Run on the right and Brown Run on the left. Degraded borrow area with drainage canals is between the streams

but a standard concrete channel was expensive and aesthetically distasteful. The channel bottom was lined with Geoweb panels filled with #57 crushed stone, which provides a solid, unerodable base. The stones trap sediments in which aquatic vegetation develops. The entire lining is now hidden under cattails, arrowhead, smartweeds, sedges, and other plants. The channel is curved to reduce velocity and to prevent the stark visual impact of a straight cut. The outsides of the curves were lined with a minimum amount of stone rip-rap to prevent bank erosion. The result is an attractive vegetated channel with a natural appearance not obtainable with pipes or concrete pads.

The several feet of impounded water was removed with a tractor-mounted pump in order to construct the channel. This exposed the remnants of the old swamp forest. An enormous mass of stumps, trunks, and branches covered the stream bottom. All of the original forest vegetation had fallen into the water, where it did not rot. It was impossible to plant trees in this debris, and removing it would have caused massive soil disturbance which would have to be ameliorated. There were many live, healthy, wetland hardwood trees upstream above the permanent pool level. We decided to let the area regenerate naturally, since seeds of most desired species would wash or blow into the area.

Creation of a New Stream Segment

A degraded upland borrow area between Crawford Mill Run and Brown Run was converted to a new branch bottom stream segment. The new stream segment was modeled on nearby natural branch bottom stream systems. Water from the permanently impounded Brown Run is diverted across the borrow area between the two creeks. The flow from this new stream segment joins the flow from Crawford Mill Run and leaves the site through the breach in the dike.

Conceptual design

The typical branch bottom stream swamp has a wide flat floodplain and very steep banks. There is essentially no ecotone between the stream and adjacent uplands. Major changes in vegetation type occur along the length of the stream. Near the mouth, a permanently flooded wide channel is flanked by marsh. Upstream, the channel narrows markedly and the marsh grades into bald cypress forest. Further upstream, the forest becomes a mix of tupelo gum, bald cypress, red maple, and sweetgum. By this point, there is no well-defined stream channel, and the stream flows only intermittently in response to storm events. Continuing upstream, the cypress and gum disappear, and the floodplain forest is dominated by the other hardwoods, including red maple, sweetgum, and tulip poplar. These changes in plant communities occur along a hydrologic gradient created by an elevational gradient - the floodplain elevation gradually rises from the mouth to the source of the stream.

A grading plan was developed to duplicate this stream pattern. The borrow area had been lowered from ~ 18 ft above mean sea level (msl) to 12-13 ft msl. The bottom of Brown Run, the water supply, was 6-7 ft msl. We wanted to lower the site just enough to allow for the maximum flows anticipated. We designed the upper reach to be inundated for up to 30% of the growing season, and the lower reach for up to 50%.

The site was divided into four tanks (Figure 2). Tank 1 is Brown Run, which remains a small reservoir to supply water to the creation area. A riser/barrel structure set at 10.5 ft msl is the primary discharge structure. Tank 2 has a deep clay lens that permanently ponds water. This allowed the area to be made into another wetland type without altering the existing grade dramatically. The elevation of approximately 12 ft msl was maintained and one foot of topsoil was spread across the area. Excess water discharges overland into Tank 3.

Tank 3 is the first segment of the created stream. Water diverted from Brown Run flows into Tank 3. It was necessary to bring the elevation of Tank 3 from 12-13 ft msl to 9 ft msl. Water drains from Tank 3 into Tank 4 through another flashboard riser system. Water leaves Tank 4 through a flashboard riser to join the flow from Crawford Mill Run through the breach in the dike. Another flashboard riser was included at the upstream end of Tank 3 to

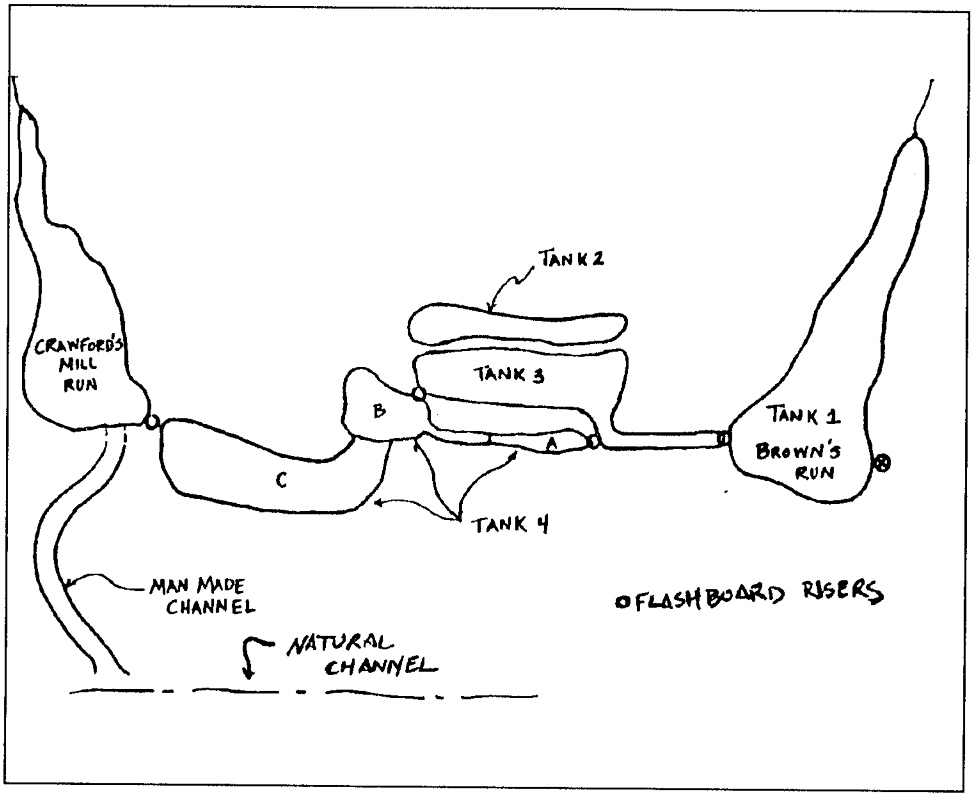

Figure 2. Conceptual design of wetland creation area (not to scale)

allow for additional overflow during heavy rainfall events into Tank 4. Tanks 3 and 4 are broad and flat with approximately 4:1 banks.

Hydrologic modeling

With limited time before construction, we developed a hydrologic model using a Lotus 1-2-3 spreadsheet on a personal computer. We wanted to know if there would be enough water to run the system for the maximum inundation regimes desired at the proposed elevations.

Each tank was treated as a basin with volumetric inputs and outputs of water. The equation for mass balance of water within each tank is:

$$S_j = S_i + Q_{in} - V_T - V_E + V_P - Q_{out} + V_{Iin} - V_{Iout}$$

where

S_j = Storage at the end of the month.

Q_{in} = Volume of inflow from contributory watershed or upstream tanks.

V_T = Volume of transpiration.

V_E = Volume of evaporation.

V_P = Volume of precipitation.

Q_{out} = Volume of flow through the outlet structure.

V_{Iin} = Volume of groundwater infiltration into tank.

V_{Iout} = Volume of groundwater infiltration out of tank.

Stage storage functions were developed to determine storage at any depth within each tank. Monthly average discharges were obtained from USGS gage. data for Durham Creek for 1965-1988. Runoffs for Tanks 1 and 2 were determined by extracting a proportional amount of the runoff from Durham Creek based on watershed area. We assumed that the rainfall and runoff characteristics of Durham Creek and Brown Run were alike, because both have primarily undeveloped watersheds in the same rainfall regime. The inflow into Tank 3 is the overflow from Tanks 1 and 2. Inflow into Tank 4b is the overflow from Tank 3. The water level in Tank 4b rises until it spills into 4a. Both tanks rise together until they overflow into 4c. All three then rise together, until finally overflowing into Crawford Mill Run.

Monthly evaporation and precipitation data were available from a nearby weather station for 22 years. Monthly transpiration rates were determined with a Penman-Monteith model of a loblolly pine plantation adjusted for variations in leaf area between pine stands and the wetland hardwood stands. Volumes of transpiration, evaporation, and precipitation were determined from surface areas derived from the stage storage functions. Infiltration of groundwater into or out of the tanks was assumed to be negligible relative to the other volumetric inputs and outputs based on sampling of the soils on site.

Storage for each tank was evaluated on a monthly basis for the 19 years of overlapping weather and flow data. The final storage for the end of each month was determined by summing the inputs and outputs. The volume of water discharged through the tank's overflow system was determined by subtracting the storage at the water level where the spillway was first activated from the final storage at the end of the month. The stage for the following month was calculated from the final storage of the previous month less the discharge. As expected, inflows were much larger during the winter months than during the summer. The model indicated that there was always ample water available to run the system at with the maximum hydroperiods desired. Water inputs could be reduced as necessary by adjusting the flashboard risers.

The hydrologic model only told us how that there was enough water available in every month to operate the wetland system for the most extreme hydroperiod desired. We are now completing a daily model that will determine the flashboard riser heights that give desired hydrologic regime. Continuous electronic water level recorders have been placed in all tanks. The data collected will be used to proof and adjust the model.

Flashboards permanently pond water, but the created wetland system often must dry completely. Lowering the water levels in Tanks 3 and 4 can be accomplished by drilling holes into the flashboards of the riser/barrel outlet structures. These holes will be set at approximately 6 inches above the average bottom of tank elevation for the two tanks. This design assumes that during the drier periods corresponding with the growing season, evaporation and transpiration outputs of water will exceed the inputs of rainfall and runoff. This will allow the remaining six inches of water to be lowered to a level at or below the bottom of the tank. If the tanks remain too wet during the growing season, the holes within the flashboard can be enlarged to reduce the drawdown time, thus allowing more time for evaporation and transpiration to lower the water levels. The holes can also be lowered to reduce the amount of water remaining in the tank that must be removed by evaporation and transpiration. The action of these drain holes will be incorporated into the new hydrologic model.

Recovery of soil and tree planting

The subsurface clays were obviously infertile, so topsoil needed to be replaced. Because topsoil makes poor dike fill, it was pushed aside in stockpiles. This soil is Roanoke fine sandy loam. The wetland soil in the natural creeks is Muckalee loam. The wetland Muckalee soil has higher organic matter and hydric properties not found in the Roanoke upland soil. However, the stockpiled soil had an unusually high organic matter content, as a result of vegetation mixed in during stockpiling. The stockpiled topsoil was spread 1 ft deep across the creation areas. It was extremely compacted by the construction equipment and could not be penetrated with a hand shovel. Tilling with conventional discs only alleviated compaction in the top 4-6 inches. Ripping again with long tines loosened the entire foot of topsoil. Tree growth would have been severely limited if compaction had not been relieved.

The upper reach (Tank 3) was planted with bare-root seedlings of green ash, tupelo gum, red maple, sweetgum, and various oaks. The lower reach (Tank 4) was planted with lesser amounts of green ash, red maple, sweetgum, and oaks. Species mixes were based on surveys of natural areas with similar hydrologic regimes.

Discussion

This wetland creation is unique in this region in several ways. It is modeled on the natural stream systems of the area. Plant species and hydrologic regimes are based on those found in the natural systems. It will have a very detailed hydrologic model. Model data can be used to set the water control structures to duplicate natural hydrologic regimes. Unfortunately, most wetland creation projects have either no hydrologic models or models too simple to be predictive or useful.

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Hydrological Considerations Associated with Constructing Wetlands in Alluvial Soils on a 31 Acre Floodplain Site in Central Pennsylvania: A Case Study, Irwin Garskof, U.S. Army Corps of Engineers, Baltimore District

Abstract

During the winter of 1990, a 31 acre floodplain along the Little Juniata River, Blair Co. Pa was developed as a wetlands mitigation site by Altoona Enterprises Inc., an industrial development authority, as part of a Corps of Engineers' regulatory enforcement action. This paper addresses hydrologic considerations specific to the development of wetlands hydrology, within alluvial soils, with substantial in-season watertable fluctuations. The details of preliminary soil investigation, groundwater data collection and interpretation, site design, soil amendments, hydrologic manipulation and vegetative plantings, are discussed. Hydrologic conditions continue to be assessed onsite, directly through well monitoring; and indirectly through annual assessment of vegetative community development and success. Problems encountered and remedies associated with site development are also discussed. Recommendations and guidance provided are applicable to wetlands construction activities, in general, within areas of seasonally variable hydrology.

Introduction

Alluvial sites, upon initial inspection, appear to be attractive wetlands creation options. These areas, in close proximity to both surface and groundwater sources, seem assured reliable wetlands hydrology; the opportunity for high water quality function is suggested by a juxtaposition generally between developed uplands and receiving waters; and they are often situated within a complex of habitat types, providing high opportunity for diverse habitat development and wildlife usage. However, a high percentage of wetlands creation attempts fail due to misassessment of in-season hydrology (USFWS 1990, 1992, Kline 1991), a problem that is particularly acute in alluvial areas where fluctuating groundwater provides the primary source of wetlands hydrology. While excessive in-season hydrologic cycling may be a constraint to wetlands development, a moderate degree of cycling, which mimics the hydrologic cycling of many natural wetlands will generally foster higher diversity and functional value within replacement systems (Whigham 1985, Niering 1989), and thus should be a design consideration. However, despite the growing availability of technical guidelines for design and construction of mitigation sites (Kusler, Quammen, and Brooks 1986, Haynes 1988, Garbisch 1989, Majumdar et al. 1989, FHWA 1990, Kusler and Kentula 1990, Kentula et al. 1991, Hammer 1992, Marble 1992), there is virtually no published data available addressing issues specific to the assessment and design of wetlands with variable in-season hydrology.

This paper presents a case study of one such project, at a 31 acre floodplain site and highlights procedures for site selection, design and implementation. Methods that are being developed or are available to modify or adjust excessive in-season watertable fluctuations at candidate sites are discussed. Research need for refinement of the process are suggested.

Background

In November 1990, a Corps of Engineers enforcement action was initiated for the unauthorized filling of 25 acres of palustrine emergent and palustrine scrub-shrub wetlands along the Little Juniata River, Blair Co. PA., by Altoona Enterprises Inc. an industrial development corporation. The project was in the final stages of completion upon discovery, and the impacted wetlands had been transferred or were in the process of legal transfer. The wetlands were adversely impacted through the construction of buildings and associated facilities, and a decision was made by the regulatory agencies to pursue compensatory mitigation as administrative remedy of this action.

Site Selection and Testing

Preliminary soil testing was performed at a number of potential sites during the spring of 1991. Sites with a spring watertable below 6-7' were rejected due to anticipated excavation costs. An agricultural parcel along the Little Juniata River was selected for more extensive soil and hydrologic investigation as water and low chroma soils were encountered in the upper soil horizons. The site consisted of a gently sloping to level 23 acre soybean field surrounded by approximately 8 acres of upland woods. Soils were primarily Linden, a deep, well drained alluvial soil, and Basher, a deep moderately well drained and somewhat poorly drained alluvial soil. Backhoe test pits were excavated on 6-22-90, at regular intervals within the field along transects established perpendicular to the stream, to a depth intersecting the apparent watertable on that date or to a minimum depth of 7', if no water was encountered. The depth to apparent watertable was measured after 4 hours.

Soil profiles were described for all pits to bottom elevation or to the depth of groundwater. 18 of 20 test pits contained silt loam in the upper horizon (generally upper 12") with clay loam and sandy loam at 2 pits. Underlying strata were typically dominated by fine sand, loam and silt loam soils with lesser amounts of clay loam, and gravel. Cobbles were encountered in all but 2 pit generally between 3-7'.

Water was observed on 6-22-90, in all but 4 pits, which were located at the more elevated western edge of the property. Monitoring wells were established at 5 of the test pits (one along each transect). Groundwater was monitored between 6-22-90 and 7-27-90, during which time levels were relatively stable. The lack of early growing season test well data was of concern due to the uncertainty of both range and timing of in-season watertable fluctuation

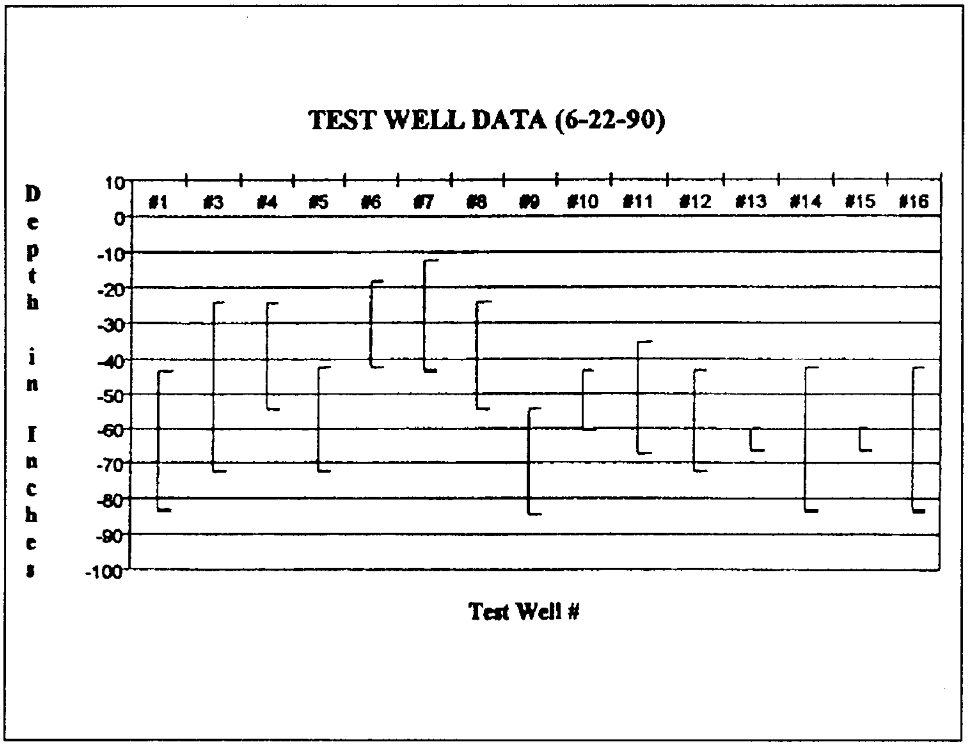
prior to the 6-22-92 readings. However, due to regulatory and administrative constraints, monitoring could not continue through the following spring.

A clue to hydrologic range was obtained from investigation of test pit soils. A relatively abrupt boundary was identified in 15 pits from predominately high chromas in the upper horizon, to low chroma matrix soils, (2 chroma soils in 13 pits and 3 chroma soils in 2 pits). Low chroma soils were encountered at a mean elevation 38" (+/- 11.3 m.d.;) below grade, suggesting reduced conditions in these horizons during a portion of the early growing season. These findings were not inconsistent with summer watertable elevations observed on 6-22-90, given time of year and expected high evapotranspiration losses; levels were on average 29" (+/- 7.7 m.d.) below these mean low chroma boundary. Although further research in this area is necessary to assess the specific quantitative relationship of low chroma soils at these depths to groundwater elevation dynamics, these findings, when considered in association with the limited direct hydrologic data available, (approx. 1 month) suggested in season watertable fluctuations in the range of 2.5 '. It should be emphasized that 'collaborative' data of this sort is not a substitute for long term ground water monitoring, which, when feasible, is the recommended approach for baseline data collection. The availability of long term data (i.e. 1-3 years) provides relative certainty that observed hydrologic conditions represent actual conditions that can be expected to prevail onsite over time, including seasonal variations of concern (Eggers 1992, O'Brien 1987).

Site Design

Sites with severe in season watertable fluctuations are probably not good candidate sites for wetlands creation unless this range is anticipated and can be modified or buffered through site design. Manipulation of certain site attributes may appreciably influence the effects of seasonal watertable fluctuation. Manipulation of the capillary fringe for example be may be a viable approach on selected sites. The depth of soil above the watertable influenced by the capillary fringe is highly variable for different soil compositions (USACOE 1987, Gerla 1992). Some clays exhibit capillary fringe influence of up to 30' (Gillham 1984, PCA 1962). Generally, mitigation sites within alluvial areas contain sandy or other moderately to well drained soils with capillary fringe influence of 6" (USACOE 1987) or less. Manipulation of subsoil structure below the A horizon, through replacement with finer grained, less permeable soils, and/or utilization of compaction techniques, may be a viable approach of maintaining soil moisture within the primary root zone during watertable loss. This method of capillary fringe enhancement is being tested by the Baltimore Corps in association with Pennsylvania State University at another alluvial mitigation site in PA, and preliminary findings should be available next summer.

In some instances, site and surrounding grades may permit contouring and drainage design that limits surface flooding; thereby reducing fluctuational



This graph indicates the depth in inches to low chroma (upper limit) and depth in inches to the water table (lower limit) as observed on June 22, 1990

range. This approach, used in this instance, will not be feasible on floodplain sites lacking sufficient topographic relief.

In pursuing site design, a hydrologic goal had to first be defined. While some in-season hydrologic cycling was desired, the estimated 2.5' range was too severe, particularly given the predominance of sandy soils. A 1'-1.5' range was considered optimum, with an upper, early in-season elevation of 0 - +.5' and with a summer, lower elevational limit of -.5' - -1' below grade, for most of the site. Elevational diversity would be enhanced with hummocks, irregular shorelines, 2 small depressional areas with shallow semipermanently flooded regimes, and broad hydrologic transition zones, with 6:1 and flatter perimeter slopes. This design presented some potential for early in-season ponding, however, it was felt that site inundation would be limited and would not permit colonization by aquatic plants even if surface soil were not exposed until mid-June; yet even this time frame would permit (delayed but viable) colonization by emergent species.

The vegetative goal of site design was to create a mixed moisture regime which would satisfy the hydrologic requirements of a FACW - OBL plant community in the bulk of the site; with FAC - FACW species dominating the higher basin elevations; and UPL - FACW species along the transitional gradient of the perimeter slopes.

Excavation depths were designed based upon a mean summer watertable elevation of 957.3', calculated from the 6-22-90 - 7-27-90 test well data. The predominate basin elevations ranged between 957.0' - 957.5', with upper and lower limits of 958.5' - 955.5'. Natural topographic relief of the site allowed for placement of a design outlet at elevation 958.5' thereby limiting early season ponding in most of the site to 1'-1.5' or less.

Site Construction

Site excavation began in November 1990 and was completed by January 1991. Approximately 102,500 cu.yds. of soil were excavated from the site. Topsoil which had been stockpiled was then redistributed as a 6"-12" layer after rough excavation was complete. The use of heavy pans and bulldozers provided some compaction of subsoils, although this was not an intended strategy. The use of large equipment is considered detrimental to preferred topsoil structure and is not recommended for final site dressing (Eggers 1992). During the following month, watertable continued to rise and by February 1991, the wetlands basin was inundated to capacity.

Site Revegetation

Viable seed banks may exist in the mitigation soil, especially if natural wetlands occur nearby (Leck 1993). Local donor sites (i.e. hydric soil), if available are also recommended as seed banks but handling and storage techniques can impact the viability of seeds present (Leck 1993). As most of the viable seeds generally are found in the upper 25cm of topsoil (Brewer 1993, Eggers 1992), stockpiling of the A horizon topsoil, should capture the bulk of viable seed bank present.

In this instance, the upper 12" of topsoil was stockpiled and subsequently redistributed. While a viable seed bank was suspected given the proximity to diverse PEM wetlands, natural recolonization was augmented with both herbaceous and woody stem plantings. Slopes above water level were winter seeded with a non-persistent perennial and annual grass mixture and mulched. Standing water persisted within the basin until April 1991, and plantings were initiated by mid May and completed by June 1991. During the summer 1991 severe drought conditions were experienced (throughout Pennsylvania), thereby stressing many of the planted species. These extreme conditions and the lack of well established surface cover, also impacted the nature and extent of initial colonization by native species.

Post Construction Monitoring

During June 1991, as part of a 5 year monitoring plan, 16 test wells were installed to assess long term groundwater cycling (Brooks and Stauffer 1992). A pattern of watertable drop in the early growing season can be seen with

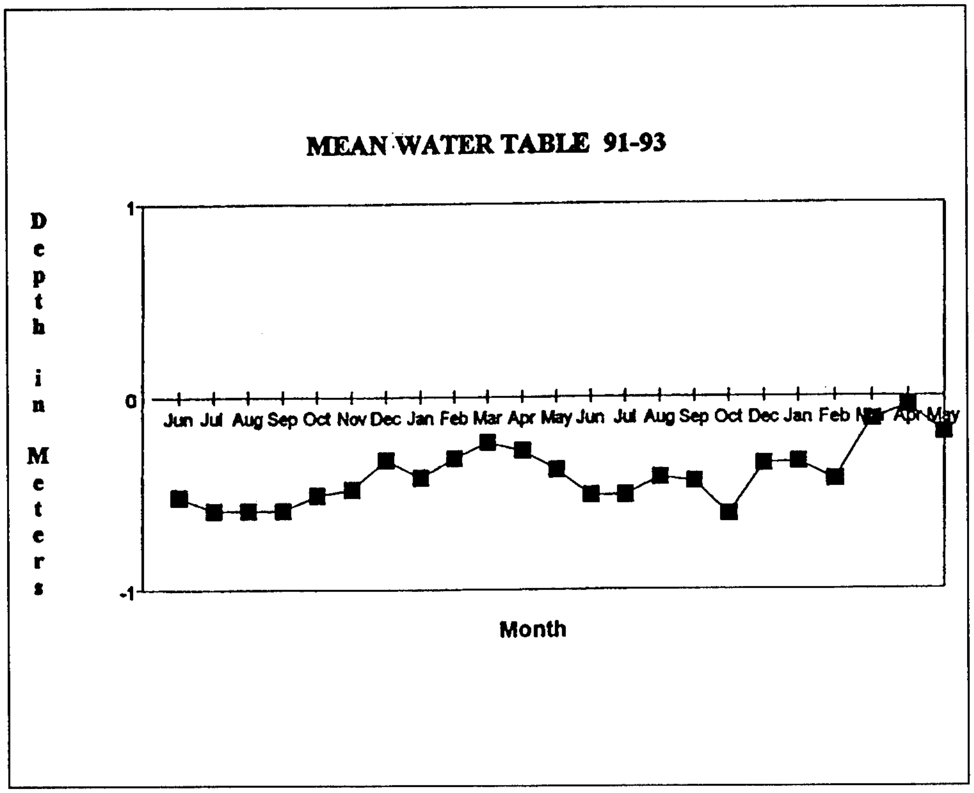
relatively stable levels throughout the later summer months. Mean range indicated for the 1992 growing season was 12" (-7.8" - -19.6"), close to the targeted range, although elevations for 1991 and 1992 were cycling deeper than expected. 1993 site conditions have been wetter to date and more closely reflect normal seasonal precipitation and expected long term hydrology.

Vegetative data correlates well with the moisture regimes found within the basin. Vegetative success was assessed (Brooks and Stauffer 1992) from data collected at 5 intensively monitored circular plots of .1 acre and 33 randomly selected estimated plots of the same size. Intensive plot contained 14 species in 1991 with coverage of 38.7%(+/- 6.4 s.d.) and with 25 species in 1992 with 66.4%(+/- 5.4 s.d.) coverage. Estimated plots contained 7 dominant plant species in 1991 and 15 in 1992. Coverage was 52.0%(+/-12.2 s.d.) for 1991 and 68.8%(+/-9.4 s.d.) for 1992. Of the 7 dominant species identified in 1991 3 were OBL, 1 was FACW, 1 was FAC and 2 were FACU. Of the 15 dominant species identified in 1992, 5 were OBL, 1 was FACW, 3 were FAC, 5 were FACU and 1 was UPL. Although 1993 data is not yet complete, a total of 44 species were identified within the mitigation area. Shrub survival was assessed (Brooks 1992) by inspection of 150 randomly tagged individuals (of 1000 planted), located throughout the basin and slope areas. In the first year, 94% of 150 tagged shrubs survived; by 1992 survival was down to 85% with losses due primarily to root erosion and browse (Brooks 1992). Plant areal coverage and diversity continues to improve with the exception of a few high hummocks of poorly colonized, nutrient poor sandy soil within the basin. Groundwater, vegetative development and wildlife usage will continue to be monitored for a 5 year period.

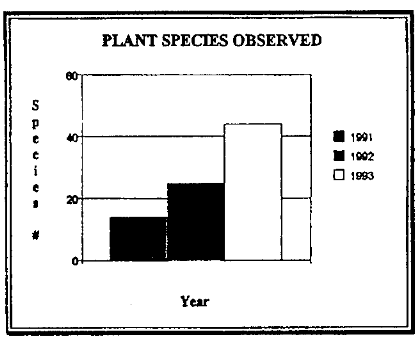
One unexpected finding of this study was a difference in pre and post construction surface soil composition. Prior to construction, the surface horizon (A) at 18 of 20 test pits was a silt loam, containing 50% or less sand. Final analysis showed 77% or more sand in 16 of 16 test locations. A number of explanations may be offered for this discrepancy, other that errors in analysis. First, as the underlying horizons were primarily sand, a high degree of mixing may have occurred during stockpiling, or during placement due to rising watertables in the basin during final grading. It has also been suggested that given repeated inundation of the basin during the winter and early spring, much of the finer silts and clays were redistributed or washed from the basin via the designed overflow. The maintenance of surficial organic soil is critical to the successful vegetative recolonization of the site, as sandy soils generally cannot maintain nutrient levels necessary for robust growth (Brewer 1993). This is particularly critical in wetlands where seasonal water fluctuations are more pronounced, as sandy soils also lack the ability to retain available moisture.

Conclusions and Recommendations

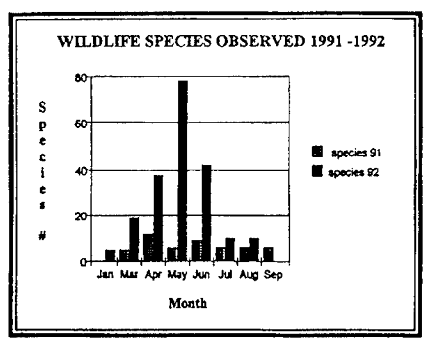
Wetland constructions within permeable soils with fluctuating in-season watertable present particular challenges for the development of wetlands



This graph indicates the mean water table depth for the period beginning June 1991, and ending May 1993, at the mitigation site. Based upon instantaneous readings at sixteen basin test wells



This chart indicates the total number of plant species present in the mitigation area from 1991 to 1993



This graph indicates wildlife observed in the mitigation area from Mar 1991 to Aug 1992

hydrology. When possible, at least 1 full year of water table data is recommended to define the range and timing of seasonal cycling. Some degree of watertable fluctuation is desirable as this mimics natural systems and adds to site diversity. There probably is an upper limit of range of fluctuation above which wetlands creation is not feasible, although this limit will also be a function of timing of water loss within the root zone. Sites with broad, in-season watertable fluctuations that cannot be mitigated or buffered, should probably be avoided. Depending upon site physiography, elevational range can be modified in a number of ways including site excavation and contouring to minimize inundation, subsoil modification to enhance capillary fringe retention and topsoil amendments to retain surface moisture. 12" of topsoil is desirable and may contain valuable seed banks, however, handling and storage may impact viability.

Continued follow-up, at this and other sites is a necessary research priority in refinement of the mitigation process for these areas. The ability to define what constitutes 'acceptable' pre-construction watertable fluctuations for potential sites; the ability to refine techniques for watertable modification in these areas; and the ability to further define the specific hydrologic ranges of hydrophytes, are some of the areas that will be advanced by these studies. 5 years of post construction monitoring is being pursued and hopefully will become an accepted minimum standard (Coates and Williams 1990, IMTF 1993).

Acknowledgements

The author would like to thank John Palmer, ERC Inc, and Dr. Robert F. Brooks for assistance in compilation of data used in this Report; Jenna Garskof for field assistance; and Shelley Bachman for administrative assistance.

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Stoplog Weir at Grassy Lake, Louisiana: Potential for Fishery Enhancement, Jan Jeffrey Hoover[1], Mark A Konikoff,[2] and K. Jack Killgore[1]

Abstract

Recommendations for operating a stoplog weir to enhance fisheries of a backwater wetland are presented. Grassy Lake, LA provides distinctive physical habitats during late spring and early summer that may be utilized as spawning grounds and as nursery areas by migratory fishes of the Black River. Fish spawn March-July and eight taxa of larval fishes exhibit significant differences in spatio-temporal patterns of abundance and habitat preferences. Timely connection with the river will enhance spawning success of commercially and recreationally important fishes, increase diversity and forage base of lacustrine fish assemblages; mid-season isolation from the river will inhibit movement of undesirable species. The structure enhances riverine fisheries by providing favorable spawning habitat in the outlet channel, that may be utilized during connection or isolation.

Introduction

Access to floodplain backwaters is critical for sustained productivity and diversity of riverine fish assemblages (Ross and Baker, 1983; Halyk and Balon, 1983; Kwak, 1988). These wetlands provide different physical habitats than those found in main channel and are intensively utilized during spring and summer as spawning grounds and nursery areas by migrating fishes (Paller, 1987; Scott and Nielsen, 1989). Providing access to these wetlands at appropriate times of the year improves reproductive success of riverine fishes (Starrett, 1951) and can replenish fishery resources of lakes. A water control structure at the outlet of Grassy Lake (Catahoula Parrish, Louisiana) provides such access for fishes of the Black River. Forty-five species of fish are known from this area (Table 1). Assemblages are taxonomically dominated by minnows (15 spp.) sunfishes and their relatives (12 spp.), many of which exploit floodplain habitats (Ross and Baker, 1983; Kwak, 1988). Riverine assemblages are more diverse than those in the lake, but several species are abundant in both: bluegill, mosquitofish, orangespotted sunfish, white crappie, and brook silverside. Suckers, rarely collected by seining, are abundant as commercial catches of buffalo from the lake (pers. obs.).

Connection of Grassy Lake with the Black River would allow diverse and abundant riverine assemblages access to spawning and nursery grounds, but habitats of larval fish and spawning chronology are undocumented.

[1] U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.
[2] University of Southwestern Louisiana, Lafayette, LA.

Table 1
Fishes of the Grassy Lake system. Species listed were collected at various times using a variety of techniques. Values are number of individuals collected per seine haul 6 Nov 92 and 3 Mar 93

	Black River	Grassy Lake
Lepisosteidae		
Lepisosteus oculatus, spotted gar	T	
L. osseus, longnose gar	T	
L. platostomus, shortnose gar	T	
Clupeidae		
Dorosoma cepedianum, gizzard shad	0.2	
D. petenense, threadfin shad	T	
Cyprinodontidae		
Cteonopharyngodon idella, grass carp		
Cyprinella lutrensis, red shiner	0.1	
C. venusta, blacktail shiner	0.9	
Cyprinus carpio, common carp		
Hypophthalmichthys sp., silver/bighead carp		
Lythrurus fumeus, ribbon shiner	0.1	
Notemigonus crysoleucas, golden shiner	0.6	
Notropis amnis, pallid shiner	1.5	
N. atherinoides, emerald shiner	T	
N. hubbsi, bluehead shiner	0.1	
N. maculatus, taillight shiner	T	
N. texanus, weed shiner	0.2	
N. volucellus, mimic shiner	T	
Opsopoeodus emiliae, pugnose minnow	0.3	
Pimphales vigilax, bluntnose minnow	2.6	
Catostomidae		
Ictiobus bubalus, smallmouth buffalo	0.1	
I. cypinelius, bigmouth buffalo		
Minytrema melanops, spotted sucker		
Ictaluridae		
Ictalurus punctatus, channel catfish	0.1	
Esocidae		
Esox sp., juvenile pickerel	0.1	
Cyprinodontidae		
Fundulus chrysotus, golden topminnow		0.6
F. notatus, blackstrip topminnow	0.9	
F. olivaceus, blackspotted topminnow		
Poeciliidae		
Gambusia affinis, mosquitofish	10.4	10.5
Atherinidae		
Labidesthes sicculus, brook silverside	1.2	1.4
Menidia beryllina, inland silverside	0.1	

(Continued)

Table 1 (Concluded)

	Black River	Grassy Lake
Centrarchidae		
Elassoma zonatum, banded pigmy sunfish	T	0.1
Lepomis cyanellus, green sunfish	0.1	
L. gulosus, warmouth	0.7	0.3
L. humilus, orangespotted sunfish	1.7	3.5
L. macrochirus, bluegill	37.3	12.4
L. marginatus, dollar sunfish		0.1
L. megalotis, longear sunfish	2.2	
L. microlophus, redear sunfish	0.1	
L. symmetricus, bantam sunfish	0.2	0.2
Micropterus salmoides, largemouth bass	0.1	0.1
Pomoxis annularis, white crappie	3.2	1.4
P. nigromaculatus, black crappie	0.7	0.3
Percidae		
Etheostoma chlorosomum, bluntnose darter	0.2	
Sciaenidae		
Aplodinotus grunniens, freshwater drum	0.1	
Total number of species	36	13
Total number of individuals	66.0	31.0

Consequently, time of connection cannot be correlated with specific fishery benefits. This paper provides: 1) spawning chronology; 2) evaluations of spawning and nursery habitats; 3) strategy for operation of structure so that fisheries are enhanced.

Study Area

Grassy Lake is a shallow (< 5 m), elongate (100 X 4800 m) wetland tributary to the Black River, in the Red River Backwater Area (Fig. 1). Pool elevation is controlled by Jonesville Lock and Dam. In 1990, a water control structure was installed at the mouth of Grassy Lake (USACE, 1991). Inlet consists of a stoplog weir 5.5 m wide capable of raising water elevation from 34.0 NGVD to 41.0 NGVD; outlet is a 1.5 m wide gated concrete pipe at 32.0 NGVD. Inlet and outlet channels have a bottom width of 3 m, with side slopes of 1 on 3. Inlet and outlet channels are, respectively, 27 and 44 m long. The structure is operated by Tensas Basin Levee District. Operation is intended to allow interchange of waters between Grassy Lake and the Black River "beneficial to the fisheries and water quality of Grassy Lake (USACE, 1991)."

Four stations were sampled (Fig. 1). These stations represent a riverine-lacustrine gradient. At 35 NGVD, the Black River is 300 m wide, with moderate current, cover consisting of timber and inundated terrestrial vegetation, and substrates of silt, mud, and clay. At water's surface, the embayment that serves as the outlet of the control structure is 9 m wide, 45 m long, and 2 m deep; submerged cover was absent, and bottom was sand, mud, and gravel

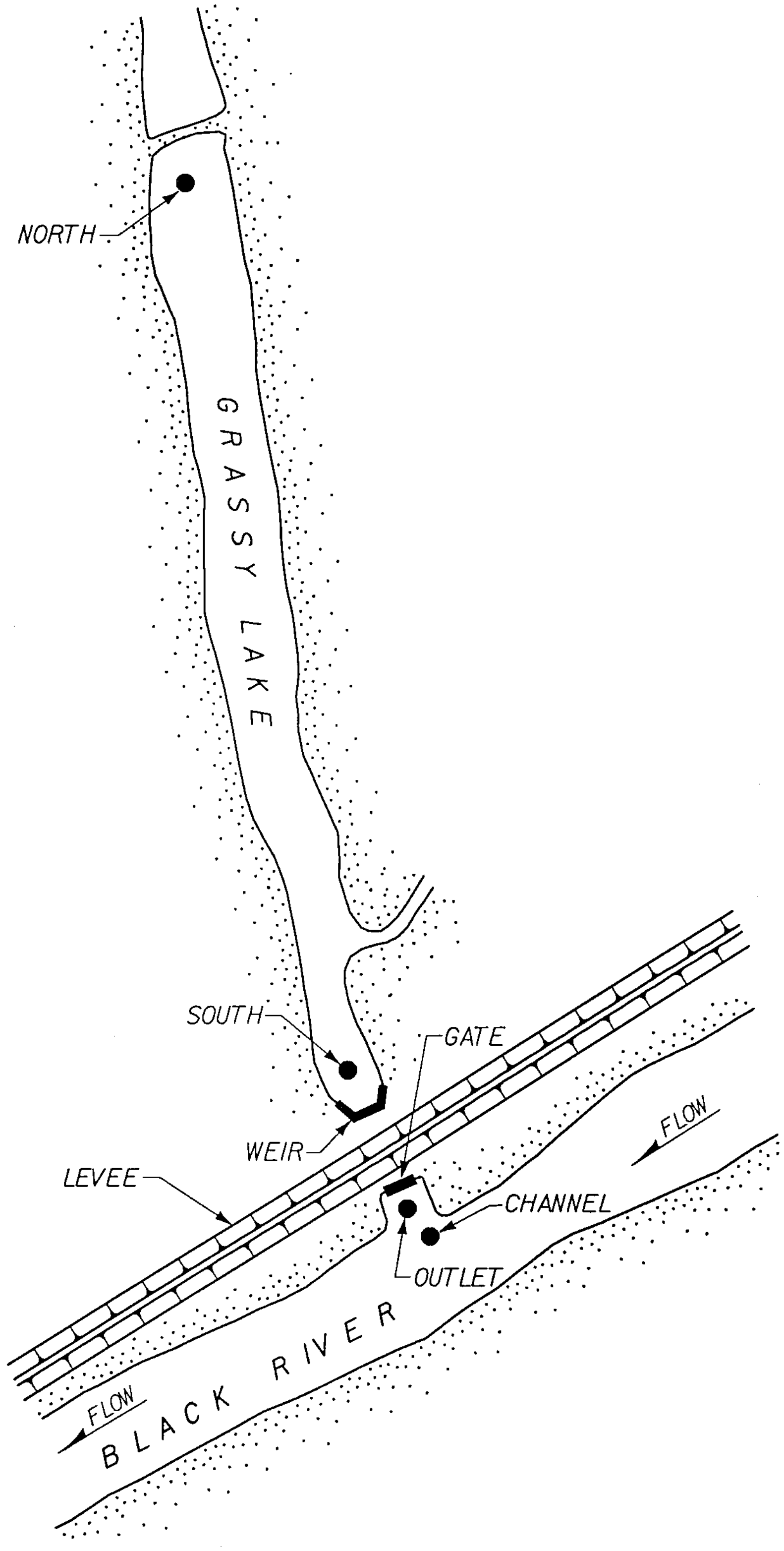

Figure 1. Grassy Lake, Louisiana

riprap. At 41 NGVD, the inlet in Grassy Lake is 15 m wide, 1-3 m deep; cover includes cypress trees, willows, and water-primrose (*Ludwigia* sp.); substrates are hard clay and mud. Upper Grassy Lake is 90-110 m wide, 1-3 m deep; cover consists of cypress, willow, and water-primrose, substrates of mud and clay. Littoral zone of Grassy Lake is shallow and densely vegetated, approximately 10-30 m wide.

Water quality and biota were sampled semi-monthly 24 Mar - 23 Jul 93. This period is typically characterized by declining river stages and rising water temperature, cues used by many species for spawning (Munro, Scott, and Lam, 1990). Sampling schedule allowed documentation of reproduction for species that spawn early in the year (e.g., suckers), midway in the season (sunfishes), and late in the year (minnows). Throughout the sampling period, all stoplogs remained in place; during most of the sampling period, river stages were so low as to prohibit connection of Grassy Lake with the Black River (without dewatering the lake). Grassy Lake was, therefore, isolated from the Black River for the duration of the study.

Water quality was sampled nearshore and offshore at each station. Parameters (and the instruments used to measure them) included:

Water temperature	(field thermometer)
Dissolved oxygen	(Hach Co. azide modification, Winkler titration)
Turbidity	(Hach Model 16800 turbidimeter)
Total dissolved solids	(Cole-Palmer DiST probe, model 1491-62)

Larval fishes were sampled with floating plexiglass light traps having vertical slots (150 mm long, 5 mm wide), "baited" with Cyalume Yellow chemical light sticks, and allowed to set overnight (Killgore and Morgan, 1994). Light traps allow point samples to be collected that are discrete and readily characterized physically and biotically. Collections with light traps provide broad taxonomic and ecological coverage of wetland fish communities (Killgore and Hoover, 1992).

Nine traps were deployed during late afternoon or early evening at each station, except in March when only 5 were set at the river and outlet (Six traps were lost so samples totaled 347). Traps were divided between nearshore and offshore sets at each station. Water depth, distance from shore, and presence/absence of submerged cover (logs, macrophytes) were recorded for each trap. Traps were recovered the following morning. Fishes were filtered through plankton netting of 505 micron mesh and preserved in 5% formalin. In the laboratory, fishes were identified to the lowest possible taxon and counted.

Physical data associated with each trap (water quality, depth, distance, and cover) were used to characterize habitats sampled at the four stations and to describe conditions associated with spawning. They do not quantify habitat availability nor identify environmental cues that regulate spawning, but illustrate differences that occur in macrohabitats among stations. Habitats are

described using principle components analysis (PCA) which ordinates 40 observations (10 dates X 4 stations) of 10 variables: temperature, DO, turbidity, TDS (means of nearshore and offshore measurements), river stage, percent cover, mean depth, coefficient of variation in depth, mean distance from shore, coefficient of variation in distance from shore (Hintze, 1991). PCA provides data reduction by plotting points (i.e., samples), originally projected in high-dimensional space (i.e., 10 variables), into space of lower dimensions (i.e., 2 components) while preserving as much of the original configuration as possible. We present an ordination based on first two principal components (PCI, PCII), each with eigenvalues > 2.00, and collectively accounting for 51% of data set variance. Variables associated with components are identified as those with the three highest "loadings" on PCI and two highest loadings on PCII. Guidelines for application and interpretation of PCA vary, and are available at different levels of expertise, including technical (Gaugh, 1982; Ludwig and Reynolds, 1988), semi-technical (Gaugh, 1993), and popular (Gould, 1981).

Analyses are provided for 8 taxa: gizzard shad, threadfin shad, buffalo, sunfishes, crappie, black basses , minnows and darters (taxa including ecologically important species). Larval fish abundance was quantified as number/trap-night. Simple linear relationships between individual habitat parameters (independent variable) and abundance of individual taxa (dependent variable) are identified using Pearson product-moment correlation coefficients (Ludwig and Reynolds, 1988). To minimize statistical bias from large numbers of zero observations (non-occurrence of larval fish), correlations are calculated from subset of samples in which that taxon occurred; this is biologically valid, since larval fishes are temporally restricted in occurrence (unlike juveniles and adult fishes which are always present) and because correlations are used to infer fish-habitat relationships (requiring elimination of habitat conditions not available to a species). Because of high variance among replicates (9/sample) and among samples (40/study), overall temporal/spatial pattern in spawning are summarized as: first and last dates of occurrence, date and station of modal abundance.

Results

Riverine and lake habitats were similar early in the spawning season, but water quality diverged after river stage decreased and temperature increased (Fig. 2). River stage was highest (39.0 NGVD) at the onset of sampling in late March and declined to minimum pool elevation (34.0 NGVD) by mid-April, which was maintained for the remainder of the study. Temperature ranged from 15-32 $^{\circ}$ C; outlet and lake were typically 2-5 $^{\circ}$ C warmer than the river through April. Total dissolved solids (TDS) ranged from 20-110 ppm and were consistently higher in the river and outlet than in the lake, with pronounced differences observed in late May and early June. Turbidity ranged from 11-69 NTU's; differences among stations were slight through mid-May, but from late May through July, turbidity was higher in the outlet and river than in the lake.

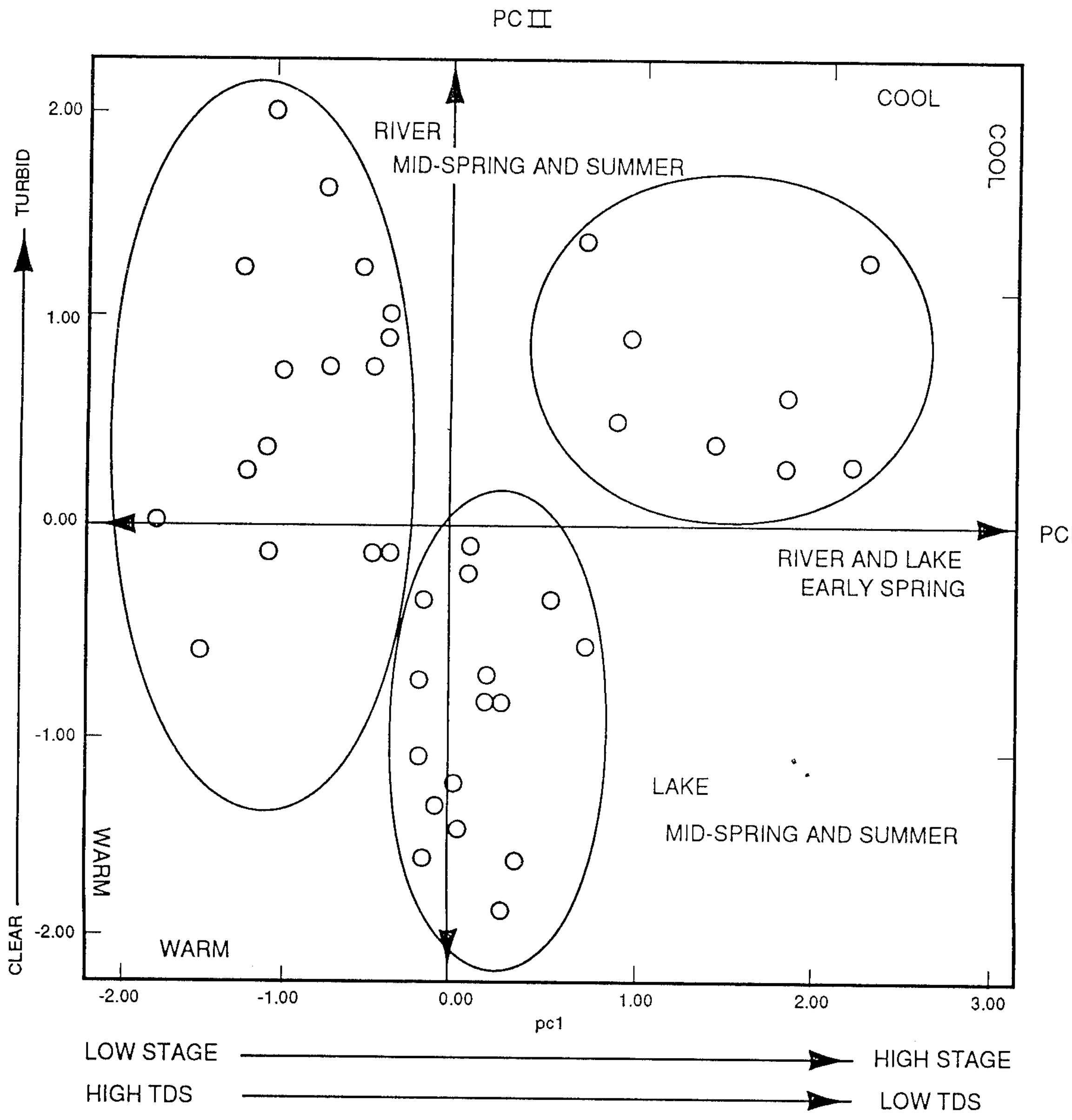

Figure 2. Principle component analysis of physical habitat data

Hypoxia was not observed, but some differences among stations existed for other habitat parameters. Dissolved oxygen (DO) ranged from 3.5-9.5 ppm, but 86% of observations were $\geq$ 5.0 ppm. Percentage of traps in cover varied. Approximately 44% of Grassy Lake traps and 22% of outlet traps were set in or near cover with little temporal variation (CV $\leq$ 10%); mean percentage of traps set in or near cover in the river was also 44%, but temporal variation was high (CV = 52%). Mean water depths at which traps were set were comparable among the four stations (62 - 96 cm), but variability at North Grassy Lake (CV = 6%) was lower than at the other three stations (CV = 22-32%). Mean distance from shore at which traps were set was greatest at North Grassy Lake (7.9 m), declined longitudinally, and was lowest at the river (1.7 m); temporal variability was high (CV = 20-39%). These data reflected longitudinal declines in width of littoral zone among the four stations.

Over 17,000 larval fish were collected. Mean catches (fish/trap-night) for the stations were:

Black River	18.50
Grassy Lake outle	157.01
Grassy Lake inlet	17.43
Grassy Lake (upper)	12.11

Mean catch for the Grassy Lake outlet is inflated by 5 traps from a single date (12 Jun 92) when each trap collected over 1200 individuals. Excluding these data, mean catch for the outlet is 44.95 fish/trap-night or more than double that of catches from other three stations.

Fishes were dominated numerically by minnows (68%) and members of the sunfish family (14%). Mosquitofish, shad, and suckers were moderately abundant (2-7%). Other families comprised less than 1% of larval fishes. Three percent of specimens could not be identified to family.

Abundances of eight different taxa of larval fishes varied spatio-temporally and were significantly correlated with 1-6 habitat variables (Fig. 3). Both shad species spawned late season, but habitat correlates were different; gizzard shad were correlated positively with TDS ($r = 0.500$, $df = 34$, $p < .01$), threadfin shad with distance from shore ($r = 0.505$, $df = 40$, $p < .01$). Minnows were collected early and late in the spawning season, but rarely in the lake; abundance was positively correlated with turbidity ($r = 0.448$, $df = 113$, $p < .01$) and TDS ($r = 0.380$, $p < .01$), and negatively with DO ($r = -0.198$, $p < .05$). Buffalo were common early in the spawning season and abundance was positively correlated with river stage ($r = 0.472$, $df = 22$, $p < .05$); none were collected in the lake. Members of the sunfish family were collected in early and late season. Sunfishes were common at all stations; abundance was positively correlated with TDS ($r = 0.372$, $df = 212$, $p < 0.01$), turbidity ($r = 0.241$, $p < .01$), and temperature ($r = 0.172$, $p < .05$), and negatively correlated with dissolved oxygen ($r = -0.230$, $p < .01$), distance from shore ($r = -0.176$, $p < .05$), and DO ($r = -0.160$, $p < .05$). Largemouth bass abundance was positively correlated with stage ($r = 0.550$, $df = 61$, $p < .01$), DO ($r = 0.474$,

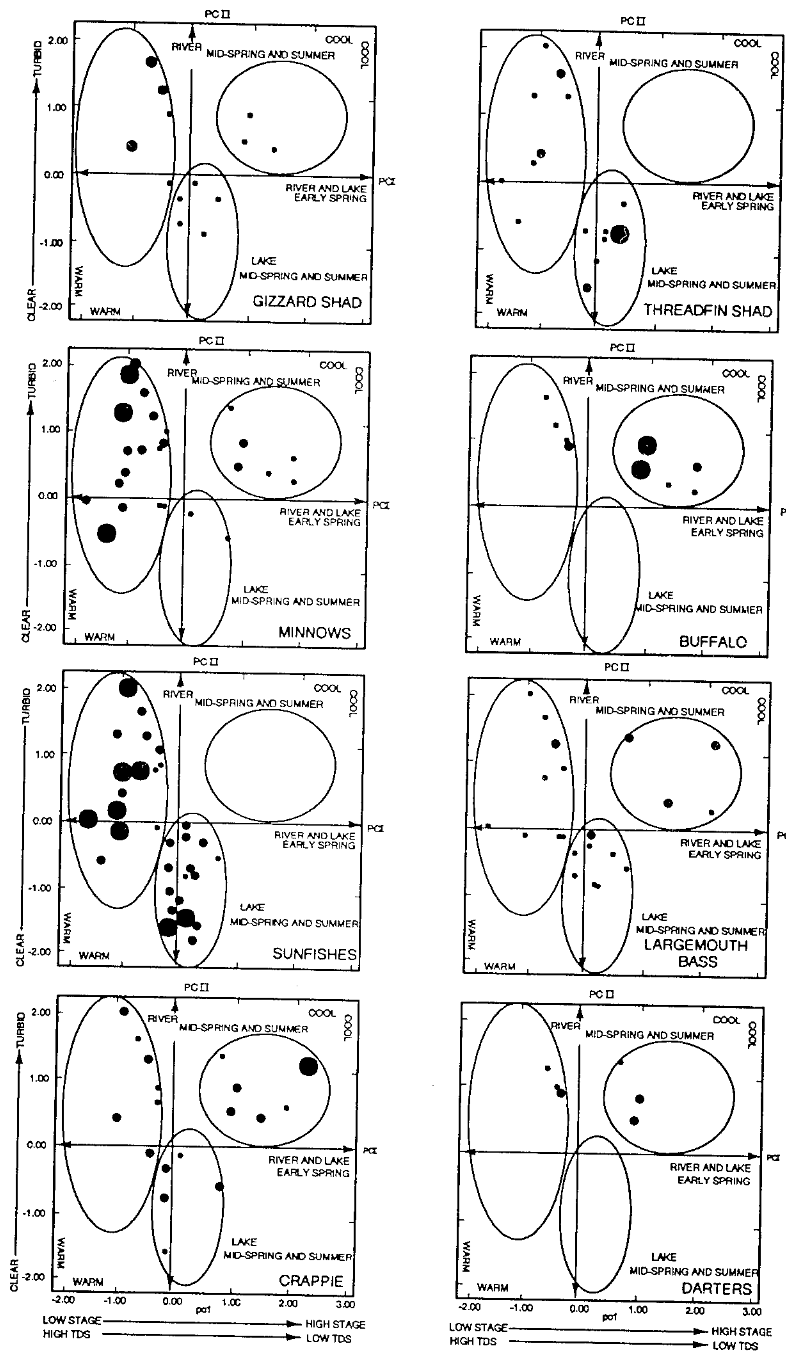

Figure 3. Occurrence and relative abundance of larval fishes projected in multivariate habitat space. Axes and ellipses are interpreted in Figure 2. Ranges of relative abundance are <1/trap-night (small circles), 1-10/trap\night (medium circles), nd >10/trap-night (large circles)

$p < .01$) and turbidity ($r = 0.377$, $p < .01$), negatively with temperature ($r = -0.410$, $p < .01$). Crappie abundance was positively correlated with distance from shore ($r = 0.266$, $df = 67$, $p < .05$), negatively with TDS ($r = -.328$, $p < .01$). Darters were collected in early and late season, but were absent from the lake; abundance was positively associated with cover ($r = 0.472$, $df = 20$, $p < .05$) negatively correlated with temperature ($r = -0.430$, $p < .05$).

Four temporal patterns of larval abundance were apparent (Fig. 4). Early riverine spawners reproduce in spring (and possibly winter) and included buffalo, darters, and gizzard shad (in respective chronological order of maximum larval abundance). Early lacustrine spawners peak in early spring but continue to reproduce throughout early summer; they include crappie and bass. Bimodal distribution of larval crappie abundance are compatible with respective spawning seasons of white and black crappie (Carlander, 1977; Robison and Buchanan, 1988). Continuous riverine spawning was observed for minnows. Bimodal distributions were represented by miscellaneous species (including an Asian minnow, probably grass carp) and for the blacktail shiner respectively. Late spawners reproduced mid-spring through early summer (and possibly later) and included sunfishes and threadfin shad. Multiple peaks in sunfish abundance were compatible with respective spawning seasons of bluegill, longear sunfish, and orangespotted sunfish respectively (Carlander, 1977; Robison and Buchanan, 1988).

Discussion

Fish habitat correlations were consistent with previous observations of early life histories: e.g., turbid water affinity of sunfishes and bass, pelagic habits of crappie and threadfin shad, floodplain utilization by buffalo (Carlander, 1969; Carlander, 1977; Robison and Buchanan, 1988). They were also consistent with previous phenologies of fish spawning.

The stoplog weir at Grassy Lake has substantial potential for fisheries enhancement. High densities of larval fishes in the outlet channel (Fig. 4) suggest that the embayment is intensively utilized by spawning fishes in the river. The aperture of the structure is sufficiently large to allow passage of adults of all species known from this area. Possible exceptions would include very large individuals of channel catfishes and drum, neither of which were abundant in our collections of juveniles and adults (Table 1) and were rare in collections of larval fishes. Water quality in the lake (Fig. 2) appears favorable to encourage river-to-backwater migrations. Submerged cover and invertebrate abundance (pers. obs.) indicate that Grassy Lake provides favorable nursery habitat.

Decisions for operating the Grassy Lake structure for fishery benefits must be based on 3 criteria: river stage, water quality, and spawning phenology. Because the lake is so shallow, stoplogs should not be removed at low river stages. In a typical year, however, stages through June may exceed 41 NGVD allowing lake-river connection with no loss of water from the lake. If slight

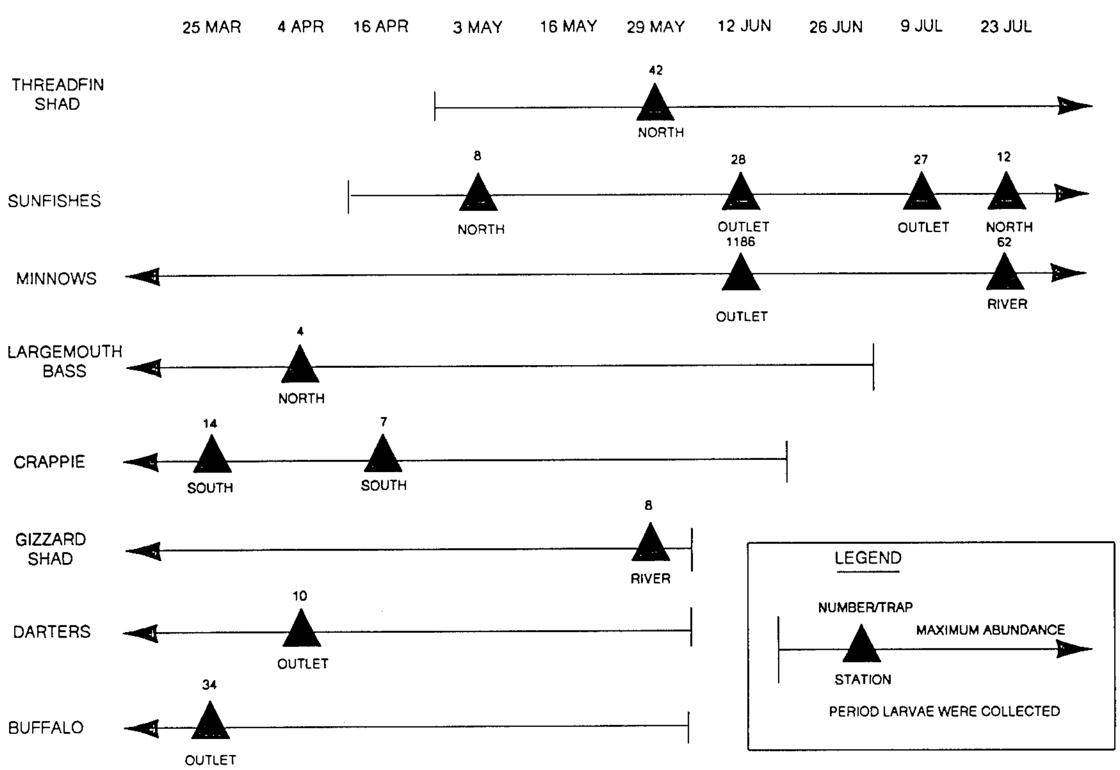

Figure 4. Spawning chronology. Horizontal line represents spawning season and are based on occurrence of larvae irrespective of station or abundance. Triangles represent spawning peaks and are based on date, station, and observed abundance of maximum catch

dewatering does take place, negative impacts to fish may not occur. No lacustrine taxon exhibited significant positive correlations with water depth, and sunfishes were most abundant in very shallow waters; threadfin shad exhibited bimodal abundance in very shallow (< 0.5 m) and deep (> 1 m) water, although this may have occurred because of seasonal offshore migrations (Allen and DeVries, 1993) and congregations in offshore habitats (this study) rather than preference for deep water.

Water quality does not appear to be limiting, but differences in water quality between river and lake could be used to promote migrations or spawning success. Stressful levels of temperature, DO, and turbidity were not observed during the study period, but abundances of 6/8 taxa were significantly correlated with one or more water quality parameters. Backwater connection during preferred habitat conditions in the lake, or backwater isolation during sub-optimal conditions, could be used to enhance lacustrine spawning success or to prevent downstream migration respectively. For example, backwater connection could provide benefits for sunfishes and bass when lake turbidity is relatively high, for minnows when lake TDS are relatively low.

Assuming sufficient river stage and favorable habitat conditions, timing of backwater connection and isolation can be used to selectively enhance spawning success of individual taxa and lacustrine fish communities. For example, based on 1991 data (Fig. 4), connection through early May, and reconnection after early July would have increased commercial fish production (buffalo), lake diversity (darters and minnows), and enhanced forage base (threadfin shad and blacktail shiner), while minimizing exchange of already abundant fish (sunfishes), exotic species (an Asian carp), and undesirable forage (gizzard shad).

Successful operation of the stoplog weir for enhancing backwater fisheries requires documentation of fish-habitat relationships and spawning chronologies. Once this information is attained, guidelines can be developed for beneficial operation. Confirmation of benefits to lacustrine fisheries, however, require documentation of long-term (between-year) variation in those data and ultimately on the passage of fishes through the structure.

Acknowledgments

Juvenile and adult fishes were collected with the assistance of L. G. Sanders and M. Potter, identified and curated by N.H. Douglas. Larval fish collections and sample processing were conducted by T.B. Shields and R. DuBois, identifications by R. Wallus. Specimens were deposited in the Museum of Zoology, Northeast Louisiana University.

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Recreation of a Mature Palustrine Wetland Forest and Vernal Pools, Phillip R. Ross and Steven M. Jones, BCM Engineers Inc., Plymouth Meeting, PA

Introduction

The wetlands recreation project presented in this paper was developed as part of a permit application to the U.S. Army Corps of Engineers (USACE) and the Pennsylvania Department of Environmental Resources (PADER) for a project in central Pennsylvania. The location of the site is shown in Figure 1. The project involved the expansion of a regional mall located in Monroe Township, Snyder County, Pennsylvania. The site with the existing mall is shown in Figure 2 and the permitted expansion is shown in Figure 3.

The application required three years for approval and the critical issue was the elimination and replacement of a 0.56 acre, isolated, palustrine forested wetland with two vernal pools. This area is designated as Area 20 in Figure 2. The permit that was eventually issued by USACE and PADER called for the creation of a total of 2.7 acres of wetlands as compensation for the encroachment of 1.6 acres of existing wetlands. The permit required a replacement ratio of 1:1 (acres created to acres encroached) for the 1.04 acre of encroachments to palustrine emergent wetlands and a replacement ratio of 3:1 for Area 20. Therefore, the wetlands creation was required to include approximately one acre of herbaceous wetlands with shrubs and approximately 1.7 acres of forested wetlands with vernal pools.

Area 20 was evaluated using deep soil borings, hydrologic assessments, field investigations by ornithologists and herpetologists, and analyses with the Habitat Evaluation Procedure (HEP) and Wetlands Evaluation Technique (WET 2.0). The mitigation plan, developed as part of the permit application, included a proposal to recreate the vernal pools in Area 20 and to transplant as many mature trees and shrubs from Area 20 as possible. These concepts eventually became part of the special conditions of the permits issued by PADER and USACE. This paper presents the techniques used to evaluate Area 20, the design objectives developed from the evaluation, the process utilized to identify the recreation area, and the plan developed to replace the wetlands eliminated by the project.

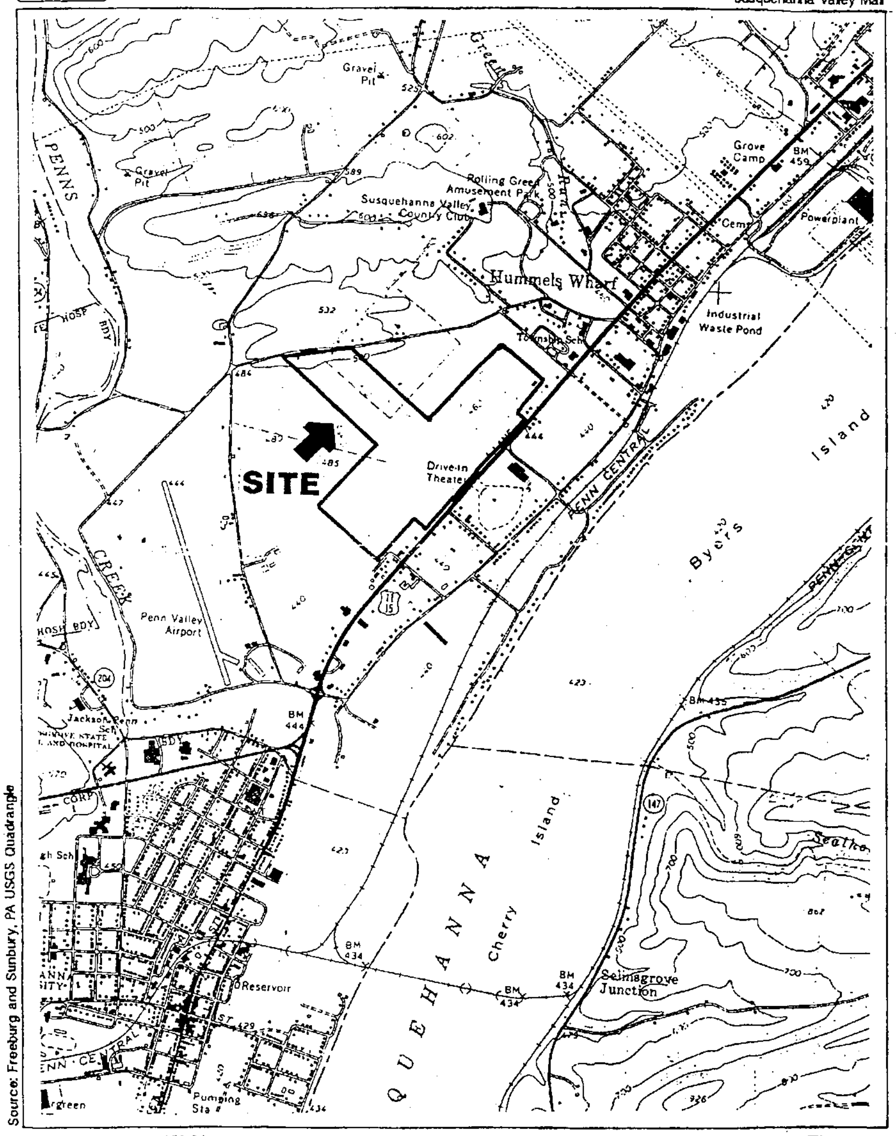
Assessment of Wetland Area 20

The wetland designated Area 20 is an isolated, 0.56 acre, palustrine forested wetland with two vernal pools. Area 20 is located west of the existing mall and at an elevation approximately 20 feet above the elevation of the mall. This upper "bench" was created in the early 1970's when the Pennsylvania Department of Transportation (PADOT) excavated a large amount of material

BCM

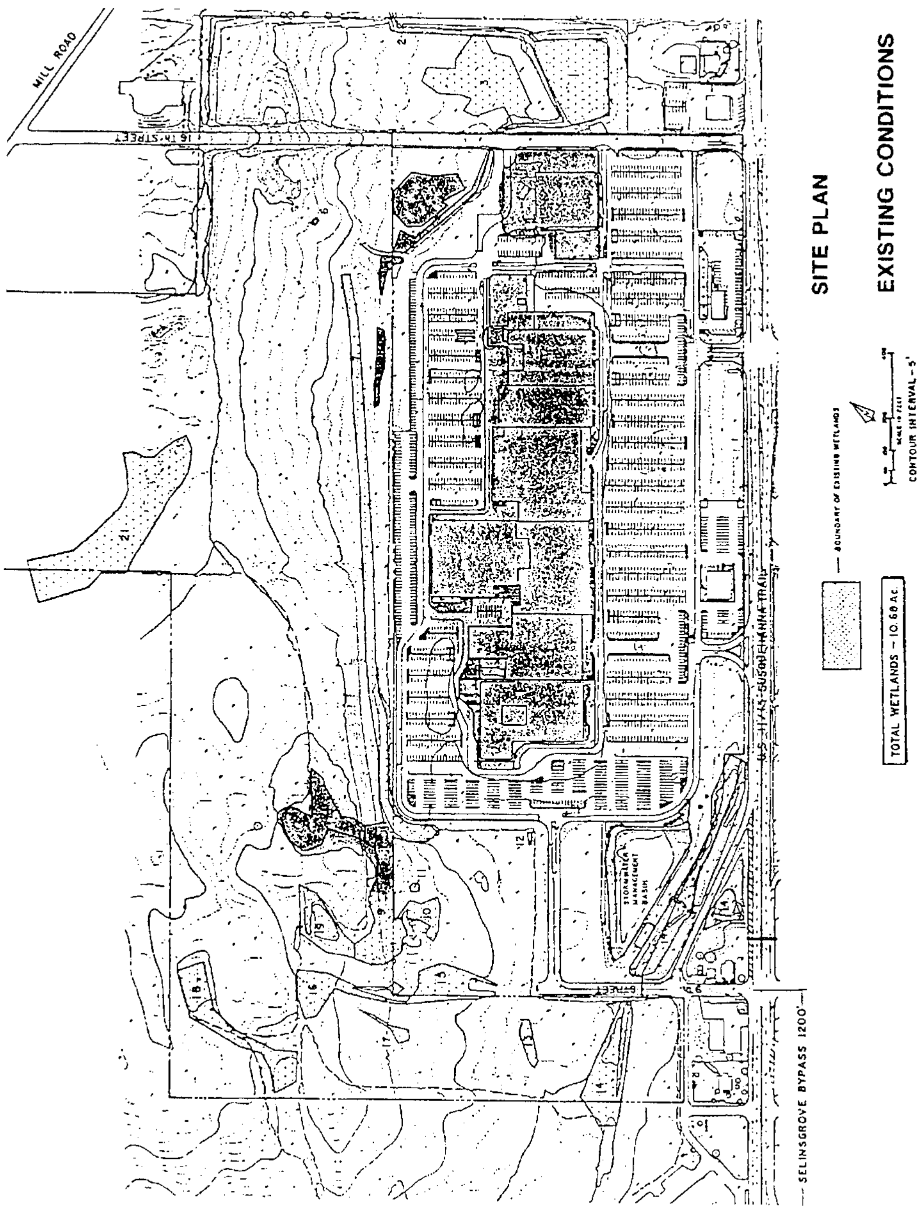
SVMA

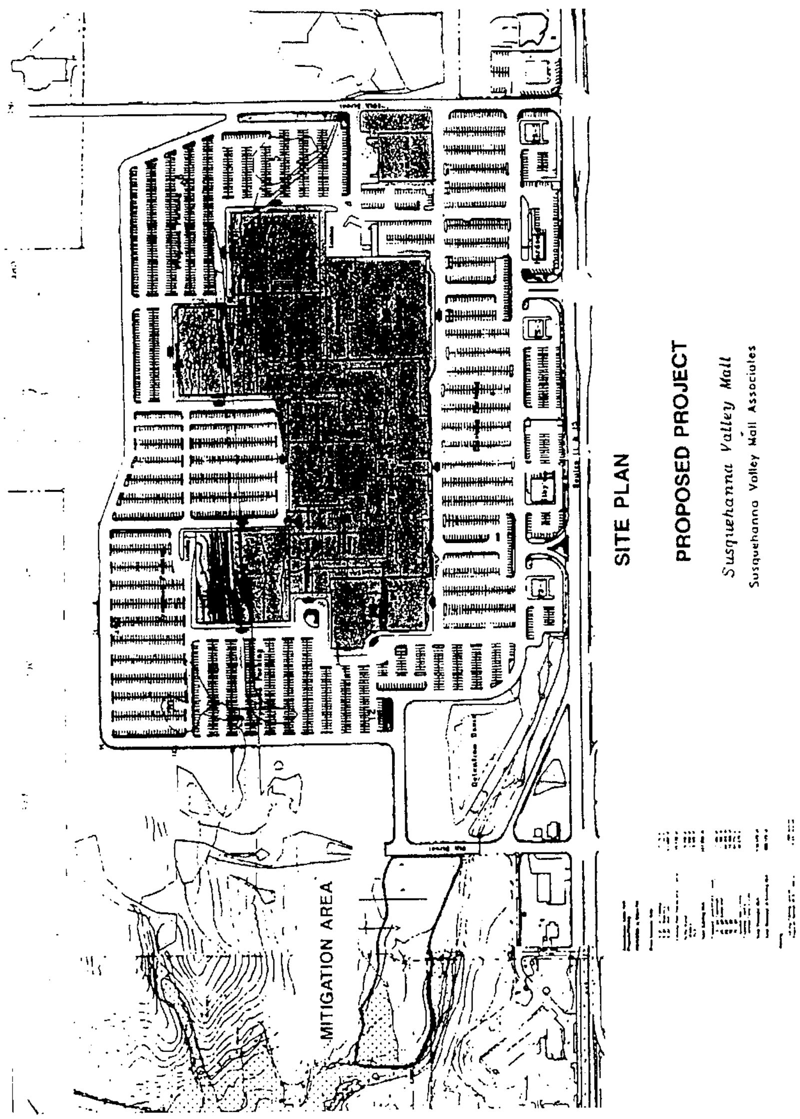
Susquehanna Valley Mall



BCM Project No. 00-6856-01

Figure 1
USGS Map


SITE PLAN
EXISTING CONDITIONS
TOTAL WETLANDS – 10.60 Ac.
CONTOUR INTERVAL-5'
MILL ROAD
16TH STREET
STORMWATER MANAGEMENT BASIN
SELINSGROVE BYPASS 1200'



SITE PLAN

PROPOSED PROJECT

Susquehanna Valley Mall

Susquehanna Valley Mall Associates

FIGURE 3

from the site. As the site plan in Figure 2 shows, a steep topographic break occurs across the western portion of the site at the edge of the PADOT excavation.

Substrate

The Snyder County Soil Conservation Service (SCS) maps indicate that soils in Area 20 consist of the Wheeling soil series. These soils are described as deep, well-drained soils with moderate permeability and moderate to high available water capacity that occur on stream terraces. Based on shallow soil borings, the actual soils in Area 20 did not match the Wheeling series profile.

In order to better characterize the soils in Area 20, a series of eight deep soil borings (up to 30 ft. deep) were conducted in and around the wetland. The results indicated that the actual soil profile in the wetland was as follows:

. 0.5 - 1.0 ft. = topsoil
. 2 - 5 ft. = clayey sand / lean clay w/ sand
. 5 - 15 ft. = silty sand / clayey sand
. 13 - 20 ft. = second layer of lean clay

The results showed that a layer of lean clay was present between 2 and 4 feet below the ground surface. The clay layer had a very low permeability and was responsible for the retention of surface water runoff that created the vernal pools.

Hydrology

The results of the deep borings also indicated that ground water was not present near the surface. This result supported the hypothesis that the hydrology of the vernal pools was supplied by surface flows rather than ground water. The location of Area 20 at the top of the PADOT grading cut indicated that the contributory drainage area was relatively small.

Hydrologic analysis indicated that the contributory drainage area for Area 20 was 2.3 acres, almost all of which came from the adjacent cultivated farm fields. The presence of the lean clay layer indicated that very little, if any, of the water in the vernal pools reached ground water. In addition, it was hypothesized that the large trees and mature shrubs utilized most of the water through evapotranspiration.

Vegetation

Vegetation present in Area 20 included: pin oak (Quercus palustris), red maple (Acer rubrum), green ash (Fraxinus pennsylvanica), river birch (Betula nigra), silver maple (Acer saccharinum), black gum (Nyssa sylvatica), silky

dogwood (Cornus amomum), common spicebush (Lindera benzoin), buttonbush (Cephalanthus occidentalis), and southern arrowwood (Viburnum dentatum). The height of the overstory trees was 40 - 100 ft. In addition, numerous understory trees ranging from 15 - 40 ft. in height were present beneath the mature trees.

The shrub layer was sparse in the vicinity of the vernal pools, but was relatively dense in the area between the two pools. No submerged or floating aquatic vegetation was present in the two vernal pools when the pools were full of water, although small patches of wetland grasses did occur at this time of year. In late summer and fall sparse growth of grasses occurred in the dry vernal pools.

During the application process, the resource and regulatory agencies were particularly concerned with the elimination of the large, old trees in Area 20. The application process, therefore, required that the functions and values of the vegetation in Area 20 be evaluated to determine whether the large trees provided a unique and irreplaceable resource to the site. This was evaluated using HEP and WET 2.0 and the results are discussed below.

Functions and values

The water quality and wildlife habitat functions provided by Area 20 were evaluated using WET 2.0 and HEP respectively. The intent of the evaluation was to determine the functions of the wetland, the value of those functions, and whether those functions and values were unique and irreplaceable on the site.

The WET 2.0 analysis focused on the following water quality functions: floodwater retention, sediment stabilization, sediment/toxicant retention, nutrient removal/ transformation, and ground water recharge. Based on the analyses performed, Area 20 provided moderate general water quality function, minimal floodwater retention, and minimal to no ground water recharge. No function was determined to be unique or irreplaceable.

Storm water runoff calculations for the 2.3 acre watershed of Area 20 were calculated using both the rational and SCS methods for the 10, 25, and 100 year storm. Based on these calculations, it was estimated that Area 20 received approximately 19,200 ft.3, 22,700 ft.3, and 30,500 ft.3 of storm water during the 10, 25, and 100 year storms respectively. The analysis demonstrated that the floodwater retention capabilities of Area 20 were extremely limited due to the very small contributory watershed.

Based on the WET 2.0 criteria, Area 20 was rated "moderate" for providing sediment stabilization, due to a lack of the following: potential erosive forces, a water table influenced by an upstream impoundment, and a substrate of rubble or erect vegetation wider than 20 feet. Area 20 was rated "moderate" for sediment/toxicant retention and nutrient removal/transformation

due to a lack of erect persistent vegetation as well as the presence of tilled soils immediately adjacent.

Based on site visits by hydrogeologists and the deep soil borings, it was determined that Area 20 was not a significant ground water recharge zone. Several obvious alluvial "benches" occur along the side valley of the Susquehanna River. The benches mark the location of the former river levels and adjacent flood plains. The materials within these benches may vary from cobbles and gravel through dense clay. The main portion of the existing mall is located on a bench that is 15 to 30 feet lower than the upper bench occupied by Area 20. The upper bench has poor to very poor internal drainage due to the prevalence of clay. Therefore, the presence of a thick clay layer under Area 20 is the reason standing water accumulates each year during the seasons of low evapotranspiration and very little water actually recharges.

The habitat value of Area 20 was evaluated using HEP models for a representative small mammal (gray squirrel), a representative bird (black capped chickadee), and a representative amphibian (red spotted newt). HEP evaluations assign numerical values to various life requisites. The values range from 0 (very poor value) to 1 (very high value. The results of the HEP analysis indicated that:

- The highest possible habitat suitability index (HSI) for the winter food life requisite for the gray squirrel in Area 20 was 0.32. This low value resulted from the presence of only one species of hard mast producing tree.

- The HSI value of Area 20 for cover/reproduction for the gray squirrel was 1.0. The high value was the result of the total canopy closure and presence of trees with a mean dbh of 15 inches or greater in Area 20.

- The HSI value of Area 20 for cover/reproduction for the red spotted newt was 0.08. This low value resulted from the fact that aquatic vegetation was virtually absent in the vernal pools (5 - 10 percent coverage) during the breeding season.

- The HSI value for food for the black capped chickadee was 0.77. The value resulted from the large number of very tall trees in Area 20.

- The HSI value for cover/reproduction for the black capped chickadee was 0.5. This value was the result of the presence of one snag of between 4 and 10 inches dbh in Area 20.

- Although certain HSI values were high, the small size of Area 20 resulted in very few habitat units available in the existing wetland.

Definition of Recreation Objectives

Utilizing the results of the analyses noted above, general design objectives were developed for the replacement wetlands. The identification of general design objectives allows the development of specific engineering details that will attain the project objectives. The design objectives established for the project are enumerated below.

- Establish two vernal pools that will hold 0.5 - 2.5 ft. of water between early spring and late summer. Pools will be dry from late summer through fall.

- Establish a layer of lean clay 2 - 5 ft. below the surface in the area of the vernal pools.

- Hydrology of the vernal pools should be supplied by surface water.

- Hydrology of the remainder of the new wetlands should be supplied by surface and ground water.

- Establish a zone of emergent vegetation at the margins of the vernal pools for herpetile breeding habitat.

- Establish clusters of trees and shrubs that provide 40 - 75 percent canopy closure for cover and reproduction for birds and small mammals.

- Establish forested habitat with as many trees, 35 ft. or greater in height, as feasible for cover/reproduction for birds and small mammals.

- Establish forested habitat with at least two snags per acre of at least 4 inches dbh for cover/reproduction for birds and small mammals.

- Include 2 - 4 additional species of mast producing trees in establishing the forested habitat.

- New wetlands should be created in a single area adjacent to a larger, existing wetland or stream complex to improve edge habitat, habitat geometry, and dispersal corridors.

Following the enumeration of the design objectives, the goals were utilized to evaluate potential sites for the recreation of Area 20.

Identification of Area for Wetlands Recreation

The policies of PADER and USACE (Baltimore District) required that the mitigation area be established on site unless it was totally infeasible to do so.

As the site plan in Figure 3 demonstrates, a number of areas north, west, and south of the mall were available for on site wetland mitigation.

Three areas were evaluated as potential mitigation sites including: an area north of the mall adjacent to an existing, unnamed tributary, an area west of the mall on the upper "bench" near the existing Area 20, and an area south of the mall adjacent to a second unnamed tributary. A qualitative first phase evaluation was performed on each area to determine the suitability for mitigation. Based on the qualitative analysis, only the area south of the mall was suitable for mitigation.

Although the area north of the mall was adjacent to an existing wetland and stream complex, sufficient acreage was not available in this area. The area west of the mall had sufficient area for the creation of the wetlands, however, the entire mitigation area would be located on the upper "bench" and would have to rely solely on surface water hydrology. In addition, the agricultural fields adjacent to this area were zoned R-2 residential and future development of these lands would have eliminated the source of hydrology to the recreated wetlands.

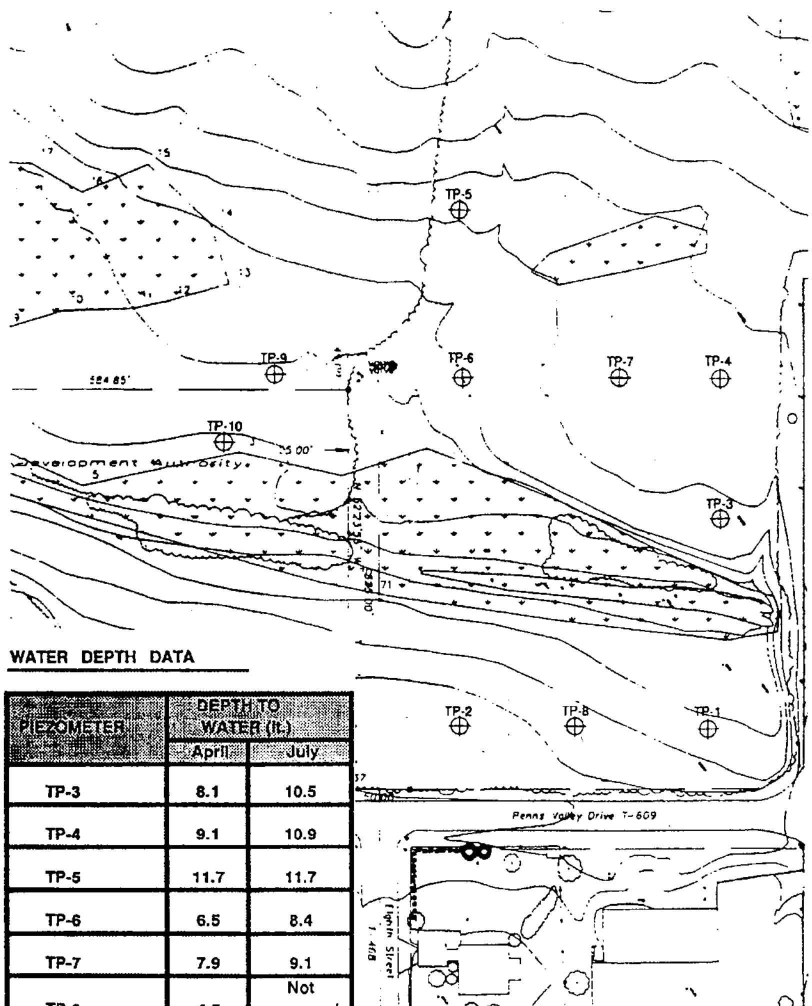
The area south of the mall was selected as the only mitigation site on the property that might meet the criteria set forth in the design objectives. In addition, the potential to locate the recreated wetlands adjacent to an existing stream was a major factor in choosing the area south of the mall. Further evaluation of the area, including ground water and soil investigations, confirmed the feasibility of utilizing this area for wetlands construction. The results of the detailed investigations were utilized in developing the engineering designs for the mitigation project. The results and the design are presented below.

Design of Recreated Wetlands

Hydrology

Ground water data were collected by installing six, 15 ft long, PVC piezometers in the proposed wetland area and one piezometer immediately up slope from the proposed wetland creation area. The location of the piezometers and data collected to date are shown in Figure 4. Data have been collected in one spring and one summer sampling event using an electronic depth to water probe. The results indicated that ground water was present from 2.5 to 9.1 feet below the surface in the spring. In addition, the depth to ground water increased approximately 2 feet across the mitigation area during the summer.

Surface water flows were estimated using the rational and SCS methods. The land up slope from the proposed mitigation area is comprised of grassy fields rather than the cultivated farm fields adjacent to the existing wetlands. It was anticipated that this would decrease the surface flow rates to the new wetland. The results of the analysis confirmed that surface flow rates to the



WATER DEPTH DATA

PIEZOMETER	DEPTH TO WATER (ft.)	
	April	July
TP-3	8.1	10.5
TP-4	9.1	10.9
TP-5	11.7	11.7
TP-6	6.5	8.4
TP-7	7.9	9.1
TP-9	4.5	Not measured
TP-10	2.5	Not measured

PIEZOMETER LOCATIONS AND DATA

FIGURE 4

recreated vernal pools would be approximately 20 percent lower than the flow rates to Area 20.

Based on the results of the hydrologic analyses, the engineering details for the mitigation wetlands included:

- Excavation of the majority of the mitigation area between 2.5 and 9.0 feet below existing grade.
- Creation of two vernal pools 1.5 to 2.0 feet above the bottom elevation of the majority of the new wetlands.
- Creation of "interception swales" in the uplands up slope from the vernal pools to capture storm water runoff from as large an area as possible and direct the water to the vernal pools.

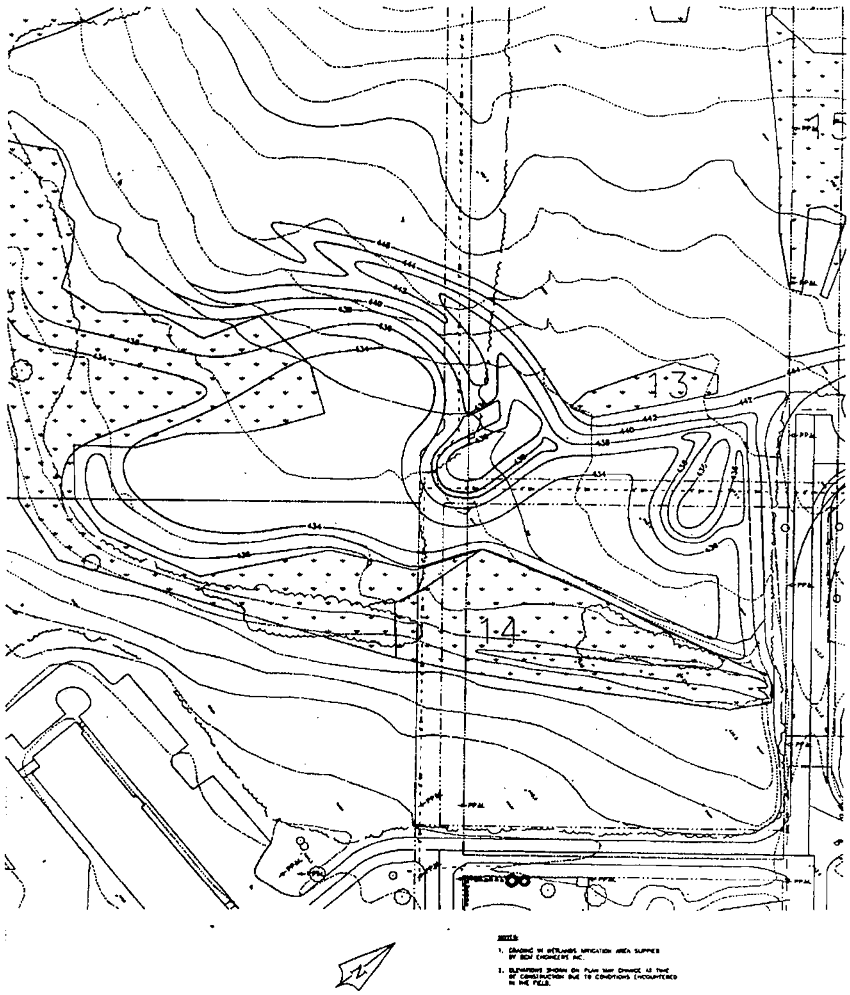
The grading plan shown in Figure 5 incorporated these details as well as the design objectives enumerated earlier. The plan, as designed, establishes contributory drainage areas of 2.4 and 2.7 acres for the northerly and southerly vernal pools respectively. Based on analysis using the SCS method, it is likely that a surplus of water will be available to the vernal pools. A surplus is desirable to counteract any increased loss of water through a more permeable substrate. In addition, the plan shown in Figure 5 includes diversion swales at the "mouth" of the pools to divert surface flow into the rest of the mitigation area when the pools are full. These features are expected to achieve the hydrologic design objectives developed for the project.

Substrate

The SCS mapped the soil in the proposed mitigation area as the Holly soil series which is classified as a deep poorly and very poorly drained flood plain soil. Actual substrate conditions were evaluated by excavating six 15 ft. pits within the boundaries of the mitigation area during installation of the piezometers. The results indicated that the following substrate types were found at varying depths below the surface:

. 0 - 2 ft. = brown sandy silt loam
. 1 - 8 ft. = brown/yellow silt loam
. 3 - 12 ft. = mottled grayish silt clay loam

The sandy silt loams found between 0 and 8 ft. below the surface matched the description of the Monongahela, not the Holly, soil series. The soil found between 3 and 12 ft. below the surface matched the Holly profile. The permeability of the Monongahela soils is too high to establish a wetland with any confidence. Based on the results of the substrate analyses, the engineering details for the mitigation wetlands included:



MITIGATION GRADING PLAN

FIGURE 5

- Field manager to determine whether proposed final elevations are in the Holly profile at the time of excavation.

- Substrate to be amended with clay from the excavation of existing wetlands in any portion of the mitigation area where final elevations are located in unsuitable soils.

- Soils in the vernal pools to be amended with the clay layer excavated from Area 20.

These features are expected to achieve the substrate design objectives enumerated for the project.

Vegetation

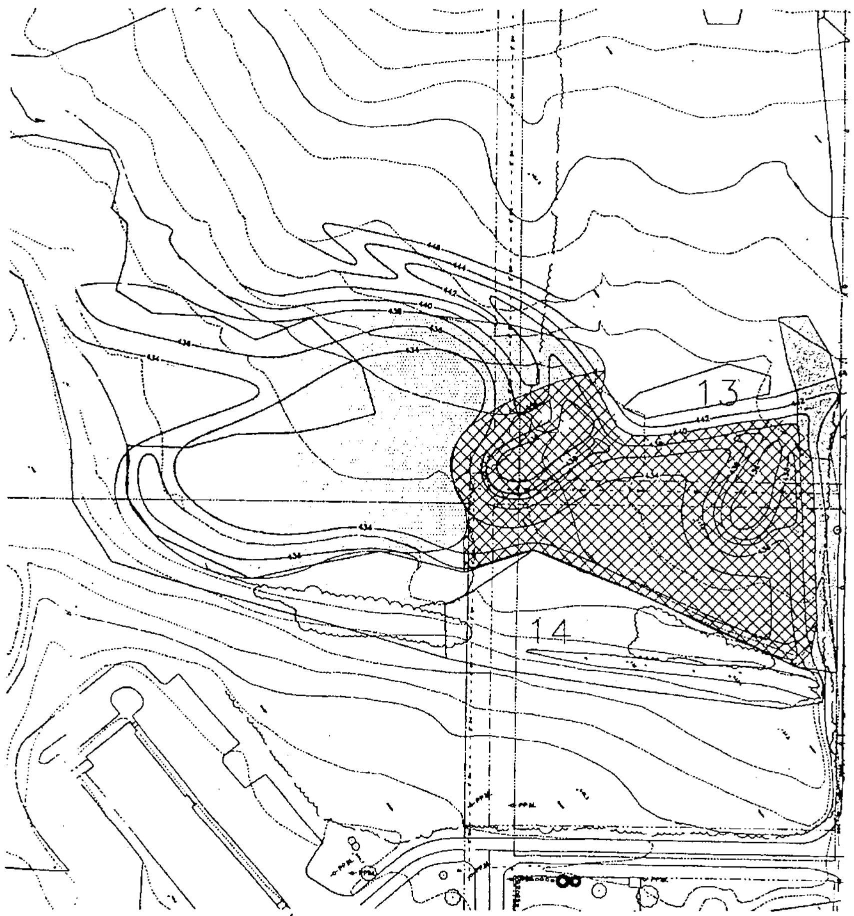
Planting design in the mitigation area included the installation of transplanted mature trees and shrubs from Area 20 as well as commercially grown nursery stock. Figure 6 presents the general planting plan and Figure 7 shows a typical area detail plan.

Material identified in the field for transplant include trees in Area 20 ranging from 1.5" - 10" in diameter (one foot above the ground). Table 1 provides a summary list of the seventy trees identified in the field. Species identified include: N. sylvatica, F. pennsylvanica, Q. palustris, A. rubrum, B. nigra, and A. saccharinum. In addition, a number of larger trees will be transplanted also. These specimens have a much lower probability of survival, however, the plan included these trees to provide snags as habitat for small mammals and birds. Numerous mature shrubs were also identified as suitable for transplant from Area 20, however, these specimens will be chosen at the time of transplant.

In addition to transplanted, mature plant material, commercially grown nursery stock was included in the plan. Table 2 provides a list of the species, form, size, and number of specimens to be installed in the mitigation area. As shown in Figures 6 and 7, the southern portion of the mitigation area will be planted with herbaceous species and clusters of shrubs. The northern portion of the mitigation area, including the vernal pools, will be planted with a combination of transplanted mature trees and shrubs and commercially grown herbaceous, shrub, and tree species. The planting densities used in the plan were 10 feet on center (FOC) for trees and shrubs and 3 FOC for herbaceous material.

Based on the results of the HEP analysis, the engineering details for the mitigation wetlands included:

- Trees and shrubs to be clustered to achieve a canopy closure between 40 and 75 percent.



LEGEND

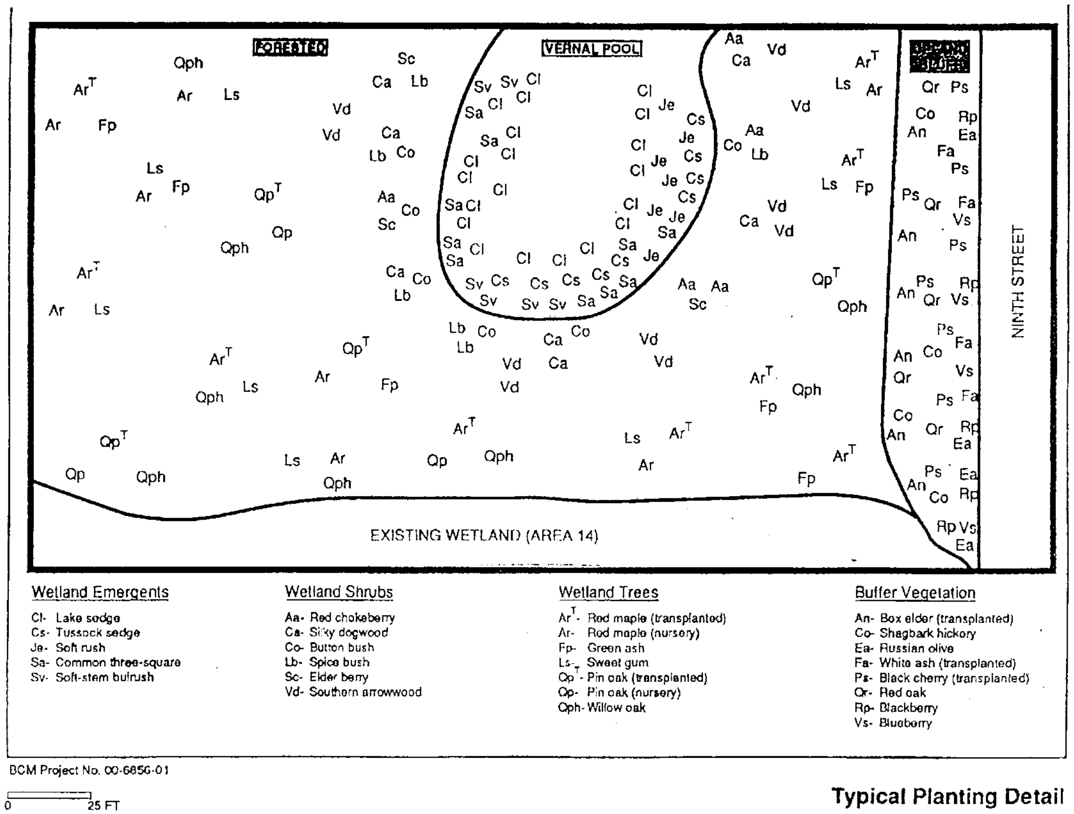
HERBACEOUS WETLAND

FORESTED WETLAND

UPLAND BUFFER

GENERAL MITIGATION PLANTING PLAN

FIGURE 6



Typical Planting Detail

FIGURE 7

Table 1
Wetland Trees Identified for Transplant

Common Name	Scientific Name	Size Range	Quantity
Mulberry	*Nyssa sylvatica*	2.0"-8.0"	16
Green ash	*Fraxinus pennsylvanica*	1.5"-9.0"	25
Pin Oak	*Quercus palustris*	4.0"-8.5"	9
Red Maple	*Acer rubrum*	2.5"-10.0"	13
River Birch	*Betula nigra*	3.0"	1
Silver Maple	*Acer saccharinum*	2.0"-8.0"	6
Total			70

- Nursery stock to be installed should include mast producing tree species in addition to the Quercus palustris to be transplanted from Area 20.

- Vernal pools to be planted with a substantial fringe of emergent vegetation at the margins.

These features are expected to achieve the vegetation design objectives enumerated for the project.

Functions and values

Table 3 provides a comparison of the functions and values of the existing wetlands to be eliminated by the project and the wetlands to be created as compensation. As the table indicates it is anticipated that the water quality and wildlife habitat functions and values provided by Area 20 can be recreated in the new wetlands. The recreation of the vernal pools and the transplantation of a large number of mature trees and shrubs are significant factors in the recreation of the wildlife values of the wetland. Although the value of some functions will be lowered until the smaller nursery trees mature, other values will actually increase due to the introduction of a wider variety of sizes and species of plant materials. The clustering of trees for canopy closure, the installation of snags, and the establishment of a vegetated fringe in the vernal pools will provide cover and reproductive habitat for small mammals, birds, and herpetiles. In addition, the creation of a larger area of wetlands adjacent to an existing stream corridor will increase edge habitat and provide dispersal corridors for wildlife. The opportunity to provide water quality functions will be increased by constructing the wetlands lower in the watershed of the site than the existing wetlands. Flood storage will also be increased by constructing the wetlands adjacent to the unnamed tributary.

Table 2
Plant Materials Susquehanna Valley Mall Mitigation

Scientific Name	Common Name	Quantity	Form	Water Regime
Herbaceous (4,000 emergents[1])				
Asclepias incarnata	Swamp milweed	300	Quart pot	At surface
Carex lacustris	Lake sedge	400	Plug	0 - 2 ft.
Carex stricta	Tissock sedge	500	Plug	0 - 0.5 ft.
Juncus effusus	Soft rush	350	Plug	0 - 1 ft.
Onoclea sensibilis	Sensitive fern	150	Transplant	At surface
Scirpus americanus	Common three square	500	Plug	0 - 1 ft.
Scirpus cypernius	Wool grass	800	Quart pot	At surface
Scirpus validus	Soft-stem bulrush	1,000	Plug	0 - 1 ft.
Shrubs (200 shrubs[2])				
Aronia Arbutifolia	Red chokeberry	30	2 - 3 ft. (container)	At surface
Cephalanthus Occidentalis	Buttonbush	40	3 - 4 ft. (container)	0 - 3 ft.
Cornus amomum	Silky dogwood	30[2]	2 - 4 ft. (bare root)	0 - 0.5 ft.
Lindera benzoin	Common spicebush	50	2 - 3 ft. (bare root)	At surface
Sambucus canadensis	Elderberry	20	2 - 4 ft. (container)	0 - 0.5 ft.
Viburnum detatum	Southern arrowhead	30[2]	3 - 4 ft. (bare root)	At surface
Forested (470 trees[3])				
Acer rubrum	Red maple	80[3]	3 - 5 ft. (bare root)	At surface
Fraxinus pennsylvania	Green ash	100[3]	3 - 5 ft. (bare root)	At surface
Liquidambar styraciflua	Sweet gum	110	4 - 5 ft. (bare root)	At surface
Quercus palustris	Pin oak	80[3]	3 - 4 ft. (bare root)	At surface
Quercus phelos	Willow oak	100	3 - 4 ft. (container)	At surface

[1] Includes herbaceous material for edges of vernal pools.
[2] Undetermined number of mature shrubs to be transplanted from wetlands to be eliminated. Final list to be provided.
[3] Does not include mature trees to be moved from wetlands to be disturbed.

Table 3
Comparison of Existing Wetlands to be Eliminated and Replacement Wetlands

	Wetlands to be Filled	Wetlands to be Created
Total Area	1.60 acres	2.72 acres
Herbaceous with Shrubs	1.04 acres	1.04 acres
Forested with Vernal Pools	0.56 acres	1.68 acres
Hydrology	Surface Water	Ground and surface Water
Habitat Values	Some wooded, shrub and edge habitat for birds. Some shallow pools and rocks for herpetiles. Isolated wetlands with no dispersal corridors for movement of wildlife.	Large contiguous wetland with significant areas of edge habitat. Vernal pools as well as rocks, logs and sucker boards for habitat. Connection to stream creates dispersal corridors for wildlife.
Water Quality Functions	Small, isolated wetlands high in watershed provide limited storm water and water quality functions.	Large, contiguous wetland low in the watershed provides improved storm water and water quality management functions.

Monitoring and Success Criteria

It is anticipated that excavation of the mitigation site will occur in the fall of 1993 and the area will be planted in spring of 1994. The area will be monitored for compliance with the permit conditions for at least five years. The criteria established to determine the success of the wetland includes not only the standard percent coverage and percent survival of plants, but also a definition of success for the vernal pools. The criteria, established through negotiations with PADER and USACE, states that the vernal pools must exhibit three consecutive "successful" years before final approval will be issued for the replacement wetlands.

The definition established for a "successful year" was that, in a year with "normal precipitation," the vernal pools retain standing water for at least two to four weeks during the spring and are dry in the fall. "Normal precipitation" was defined as plus or minus one standard deviation from the 30 year mean precipitation as recorded at the NOAA Selinsgrove Climatological Data Station. If non-normal precipitation conditions occur, that year will be monitored but will not be evaluated as successful or unsuccessful. Only those years in which "normal" conditions occur will be evaluated as successful or unsuccessful. If by the fifth year three consecutive, evaluated years have been achieved, the mitigation site will be considered successful. If three successful consecutive, evaluated years have not been achieved by the fifth year of monitoring, the monitoring period will continue until such a condition has been achieved.

Conclusion

Although the project described is relatively small in size, a number of analytical tools were used that normally are applied only to larger projects. Utilization of a multi-disciplinary team to evaluate the functions and characterize the resources of the existing wetlands proved invaluable in establishing design objectives for the wetlands construction project. Additional monitoring of the ground water would be very useful. However, the reality of mitigation construction projects for the industrial, commercial, and residential sector is that time is at a premium and design and construction must be accomplished on limited data. The commitment to recreate important aspects of the existing wetland, including transplanting mature trees, and to develop a detailed characterization of the existing wetlands and the proposed mitigation site has contributed significantly to the successful design of the project.

Stream Restoration Project Designs That Protect Wetlands, Chester A. McConnell, Wildlife Management Institute, Lawrenceburg, Tennessee

Stream-wetland ecosystems are an important part of the hydrologic cycle that keeps the earth's water in constant circulation. These ecosystems provide many important biological, chemical and physical benefits, including fish and wildlife habitats, water quality enhancement, flood reduction, ground water recharge and discharge and aesthetics. Such benefits are unquestionably tied to the presence, movement, quality and quantity of waters in stream-wetland ecosystems. These ecosystems are essential to many plants and animals, and they need and deserve much more protection and enhancement than they have received historically. The functions and values of streams and wetlands have been described in numerous publications and are amply summarized by Sather and Smith (1984).

Hydrology is the most important determinant for the establishment and maintenance of specific types of wetland processes. A key to protection of floodplain wetlands is protection of streams. While gradual change in hydrologic conditions is natural, numerous stream-wetland ecosystems in the lower 48 states have been rapidly and extensively altered by humans. During the past 150 years, the modification, development or "improvement" of at least 200,000 miles of our Nation's waterways has occurred. Primary purposes for these actions were to drain lands for agriculture, reduce flooding and provide for waterborne transport of goods. One result was drainage of about 130 million wetland acres (Arthur D. Little, Inc. 1973). The severe impacts of radical stream modifications on stream-wetland environments, reported in numerous publications, have been summarized by Simpson et al.(1982) and Marzolf (1978).

The historical assault on streams and wetlands is not near culmination if certain interests are satisfied. A long list of projects authorized by the U.S. Congress is awaiting implementation and planning for new projects continues. One example includes efforts by the Lower Mississippi Regional Comprehensive Study Coordinating Committee associated with the Corps of Engineers (COE). This committee prepared a long-range planning guide expressing an additional need, by 2020, for 26,331 miles of channel "improvements" for flood relief; 43,610 miles of channels and ditches for draining farm lands; and 1,357 miles of channel "improvements" and new channels for navigation (Lower Mississippi Region Comprehensive Study Coordinating Committee 1974).

Widespread damage and destruction of stream-wetland ecosystems has created demand for change. A survey by Times Mirror Magazines points out that the public clearly places a higher priority on wetland protection than on economic development and private property rights (The Roper Organization, Inc. 1992).

In recent years, some planners have sought solutions to flooding and stream flow problems by focusing on restoration and maintenance of hydrological conditions. Two such nonstructural efforts involve protection of natural stream-wetland ecosystems of the Charles and Neponset Rivers, Massachusetts.

The Charles River plan was based on new insights in the field of hydrology, and on new sensitivity to environmental alteration. Channelization of the river was considered ineffective and too expensive. Instead the selected plan involves acquisition of 8,422 wetland acres along the 80 mile reach of the Charles River between Boston and Cambridge. The wetlands are being acquired to preserve their natural flood storage capacity. Recreation and fish and wildlife benefits will also be protected (U.S. Army Corps of Engineers 1972).

The COE (1972) determined that a loss of 40 percent of the wetlands in the Charles River Basin would increase flood damages by at least $3,193,000 annually. Loss of the entire 8,422 acres of wetlands would result in average flood damages of $17,084,606. For this study the COE determined the most economical way to control flood losses was to protect wetlands.

The Neponset River study also indicated that a significant increase in downstream flood stages would occur with loss of wetlands. The basin-wide floodstage increase for the 100-year flood stage was predicted to range from 0.15 meters with a 10 percent loss of wetlands to 0.9 meters with a 50 percent loss (Anderson-Nichols and Co., Inc. 1971).

Unfortunately, nonstructural alternatives do not apply in all situations. In these cases, the most environmentally sensitive structural designs should be used. Where unfeasible or inappropriate to address flow problems with no action or nonstructural alternatives, the Stream Obstruction Removal Guidelines (SORG) offers a sound alternative (Stream Renovation Guidelines Committee 1983). Where properly applied, SORG procedures correct stream flow problems in an environmentally sensitive manner.

Developed in 1983 by a joint committee of The Wildlife Society and American Fisheries Society in cooperation with the International Association of Fish and Wildlife Agencies, SORG requires several sequential actions: (1) An interdisciplinary (ID) team of experts is established who are familiar with conditions in the stream locality; (2) The ID Team classifies stream reaches according to the degree of flow problems and biological sensitivity. Stream segments are classified Conditions One through Five based on descriptions, photographs and drawings in the SORG manual. Condition One stream segments have acceptable flow and no work is required. Worst situations are Condition Four where stream segments have major blockages causing unacceptable flow problems; (3) After classification, the SORG manual specifies methods for removing obstructions for each of the three conditions where work is allowed. Hand tools and light equipment are specified for use in stream segments with minor obstructions (Conditions Two and Three). Heavy equipment may be used where major flow obstructions occur (Condition

Four); (4) The ID Team monitors ongoing work to insure compliance and completed work to determine maintenance needs; and (5) Maintenance is conducted in accordance with the SORG manual.

A cross section of projects where SORG has been successfully applied to restore or protect stream-wetland ecosystems are summarized. Wolf River in Tennessee was one of the first projects where an early version of SORG was used. This project involved 53 miles of the Wolf River that had not been altered. Fallen trees and other debris caused obstructions in some stream segments. Sediment from excessive upland erosion flowed into the river forming complete blockages of some segments for several thousand feet causing stream flow to enter the floodplain. Bottomland forest and farm lands were damaged and small craft navigation was impaired (McConnell 1979).

In an effort to restore stream flow, the Soil Conservation Service (SCS) initiated a radical project that removed all trees from one bank, removed all debris and sediment from the stream channel and cut pilot channels across some meanders. Wolf River was being severely damaged and wetlands were being drained. Following objections from the Wildlife Management Institute, SCS substituted SORG to complete the project. Normal hydrology was restored causing the stream-wetland ecosystem to function naturally. Several thousand acres of various wetland types and riparian habitats were protected and many natural stream segments remained unaltered (McConnell et al. 1980). Several years after natural flow was restored the river became a major recreation area for canoeist and fishermen.

Hatchie River, designated a scenic river by the state of Tennessee, flows in its natural condition. However several tributary streams channelized by SCS annually deposit many tons of sediment into the river. The Hatchie was beginning to develop similar problems as the Wolf River. To prevent minor problems from becoming major, Tennessee Department of Conservation developed a preventative maintenance program based on SORG principles. An ID Team determines maintenance needs and a crew, using light equipment, removes or relocates any obstructions identified on the 165 mile reach. The program, initiated in 1980, has maintained normal stream flow and protected the vast wetland complex at low costs.

The COE has applied SORG to several projects. The East Fork Tombigbee River experienced damages similar to those described for the Wolf River. Four tributary streams had been channelized causing many tons of sediment to flow into the meandering East Fork. COE's Mobile District used SORG techniques to restore flow and protect floodplain wetland resources along 53 river miles (U.S. Army Corps of Engineers 1984). Conservation groups and agencies who reviewed the work were favorably impressed. However the channelized tributaries continue to cause sediment problems for East Fork.

The Corps' Mobile District is also using SORG to improve flow in Luxapalila Creek in Alabama and Mississippi. In the 1940's a channel had been constructed in the creek floodplain but had subsequently filled with sediment

for several miles. Stream flow reverted to the downstream 29 miles of old natural channel. The COE altered plans to rechannelize after much public resistance. SORG was substituted for channelization with the intent to improve flow in the natural stream channel and protect the vast stream-wetland ecosystem (U.S. Army District, Mobile 1991).

Mayfield Creek in Kentucky is another project where SORG was substituted for channelization following long-term public opposition to destruction of environmental values. Channel obstructions are similar to those described for Luxapalila Creek. This project was planned, and work is being performed by the COEs' Memphis District. The project is designed to restore flow in both the old degraded dug channel and portions of the old natural channel. A low flow diversion weir will be constructed to divert flows through portions of the old natural channel to protect fishery habitat and ensure recharge of wetlands (U.S. Army Corps of Engineers, Memphis District 1990). This project demonstrates that environmentally sound solutions can be developed to solve problems created by channelization and improper landuse. In this case a radically altered system is currently being reconstructed to restore some of the stream-ecosystem functions.

The COE's Memphis District also reevaluated the L'Anguille River project in Arkansas and substituted SORG for a previously authorized channelization project. Plans are to remove some debris and selected sediment deposits from the 95 mile long natural channel to reduce flood damages (U.S. Army Corps of Engineers,Memphis District 1985). The goal is restoration of historic hydrology to the 40,356 acre stream-wetland ecosystem.

The Obion-Forked Deer Basin Authority is applying SORG techniques to 399 miles on 20 streams in the Obion-Forked Deer Basin in Tennessee. Most of these streams were channelized from 1914 to 1920, and received little maintenance until the 1970's. Consequently many channels became obstructed with debris and sediment from the highly erosive watershed. Stream flows diverted onto the floodplains in many locations contributed to the death of bottomland forest on thousands of acres and excessive wetness of some agricultural fields (Regional Economic Development Center 1982). Over time, however, trees grew back on the banks, structure developed in the channels and emergent wetlands formed causing some improvement in environmental conditions. Where SORG principles have been properly applied the severely degraded system is slowly improving.

One of the better efforts where SORG principles are being applied is a program developed by the West Eight County Association of Soil Conservation Districts (West Eight) with technical and financial assistance from SCS and Tennessee Valley Authority. Recognizing that soil erosion is a major cause of stream blockages, West Eight requires that watershed erosion be reduced to a maximum of 5 tons/acre/year before stream renovation activities begin. Each participating county must have federal floodplain insurance and provide 50 percent of costs for stream work. Riparian landowners are required to execute 10-year "cooperator maintenance agreements" prior to stream work.

Agreements protect riparian zones and require landowner maintenance of renovated channels. A project review group of government agencies and private conservation groups work closely with West Eight to assist in planning and monitoring field work to assure compliance. The program has restored normal stream flows to over 100 miles on 7 streams since 1984 at a cost of about $6 to 9 thousand/mile (Porter 1988).

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Two-Dimensional Hydrodynamic Modeling of Wetland Surface Flows, Robert A. Evans and Lisa C. Roig, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS

Abstract

A two-dimensional, vertically integrated model of free surface flow has been developed for wetland applications. Surface flow models are used for wetlands restoration design, operation, and management. This demonstration illustrates special features of the numerical model which are required to adequately simulate wetting and drying of the marsh surface, and shallow flow through emergent vegetation. The flexibility to modify numerical grid resolution is particularly useful in wetland environments where engineers must address a variety of environmental and operational questions. In this paper, example applications are used to demonstrate the hydrodynamic model for design of control structures and operational procedures.

Introduction

The relationship between hydrodynamics and the flora and fauna of a wetland must be understood as part of wetland restoration and design. Certain plants and animals thrive under specific conditions of water and soil salinity, frequency of inundations, and water velocity. The effects of wetland restoration on nearby public and private property must also be considered. Hydrodynamic models are useful tools for understanding the effects of engineering projects on wetland circulation. The Waterways Experiment Station Hydraulics Laboratory (WESHL) has developed a two-dimensional, vertically integrated finite element model system (TABS-MD) which will accurately model the surface flow in wetlands. In addition, a graphical interface (FastTABS) has been developed which permits the user to rapidly analyze various wetland plans. FastTABS provides both pre- and post-processing functions.

Modeling System

TABS-MD

The TABS-MD hydrodynamic modeling system consists of a group of models which include hydrodynamics, transport, and sedimentation. The hydrodynamic model, RMA-2, was originally developed by Norton, King, and Orlob (1973). It has been further developed by Norton and King, of Resource Management Associates (RMA), and by the WES Hydraulics Laboratory to include state-of-the-art modeling features. A detailed description of TABS-MD can be found in Thomas and McAnally (1985).

RMA-2 computes the water surface elevations and vertically-averaged flow velocities using the finite element method. RMA-2 computes both steady-state and dynamic solutions. Boundary conditions are specified as flow rates, water elevation, or water velocity. A variable time step can be specified because the model is fully implicit. Hydrodynamic parameters such as Manning's n and eddy viscosity can be defined by element type or by individual elements or nodes. These parameters may be temporally and spatially varied. An essential modeling feature for wetland modeling is the intermittent removal and addition of elements which become dry and wet, respectively, during the simulation period.

FastTABS

The FastTABS computer program was developed by the Brigham Young University Engineering Computer Graphics Laboratory in cooperation with the Hydraulics Laboratory, Waterways Experiment Station. It is a graphical pre- and post-processor for the TABS-MD hydrodynamic modeling system. This allows the wetland designer to quickly and easily construct a finite element mesh, generate hydrodynamic results with RMA-2, analyze the results for validity, and perform modifications. Results can be presented on an areal basis by contouring (either by contour lines or color shading) or on a nodal basis via time-series plots of water surface elevations and velocities. Results can be saved as graphics files (PICT, PostScript, etc.) and in spreadsheet format.

Case Studies

Bodkin Island, Maryland

Bodkin Island is located in Eastern Bay, Maryland (part of Chesapeake Bay). This island, which provides ideal nesting habitat for the Black Duck, has eroded from a size of 50 acres in 1847 to approximately 0.94 acres in 1993. The reduction is due to wind wave erosion. Bodkin Island is to be enlarged to 4.8 acres to enhance black duck habitat. The primary objectives are (a) to reestablish black duck brood habitat, (b) to improve and enlarge nesting habitat, and (c) to stabilize the island. The island will be enlarged, shaped, stabilized, and vegetated using clean dredged material.

A numerical model study was conducted to determine if the enlarged island would cause significant changes in the flow field around Bodkin Island. The stability of intertidal ponds and channels in the interior of the design island was investigated. Significant features of the plan include interior channels and ponds and a breakwater to the north of the enlarged island. A criteria for successful design was that the enlarged island should not significantly influence near field flow patterns. Nearby shellfish habitat is sensitive to changes in flow velocities. The water flow in the interior channels and pond should be neither erosive nor high enough to sweep young hatchlings out to deep water.

The simulation domain included the entire Eastern Bay. A tidal boundary was defined from Kent Point to 1 mile south of Wades Point consisting of a repetitive, sinusoidal tidal wave with a range of 2 feet and a period of 12.5 hours. The time step used was 0.50 hours and the total simulation time was 50 hours. Figures 1a and 1b show the maximum ebb and flood velocities under plan conditions, respectively. Note that, during the tidal cycle the interior of the island is completely inundated, while at low tide, only the channels and ponds remain wet.

The results of this numerical model study showed that the enlarged island would not affect flow velocities in the shellfish habitat. Flows in the island interior will not cause erosion or black duck chick mortality. Interior flows are sufficient to insure proper water circulation in the tidal pools and channels.

Galilee bird sanctuary, Rhode Island

The Galilee Bird Sanctuary is approximately 130 acres of salt marsh. In 1956, the Galilee Escape Road was built, dividing the area into two distinct tidal regions connected by two 30 inch culverts. The area north of the road (approximately 30 acres) continues to function naturally as a salt marsh. The area south of the road (approximately 90 acres) has become less saline and has been overrun by shrubs and the common reed, *Phragmites australis*. By increasing salt water inundation of the south region, the *Phragmites australis* would be eradicated and more beneficial species could be reestablished.

The plan to increase saline circulation includes the installation of two 8'x10' box culverts connecting the north region with the south region. The questions to be answered are:

a. Are the two culverts large enough to ensure that the majority of the area is inundated during the tidal cycle?

b. Will there be a need for a control gate to insure that adjacent private property is not flooded?

c. Will the velocities in the design channels induce scouring?

d. How much area will be inundated for sufficient periods to eradicate the *Phragmites australis*?

Example RMA2 simulation results are shown in Figure 2. The tidal boundary along Bluff Hill Cove was specified as a repetitive sinusoidal tidal wave ranging from -1 foot MLW to +2.85 feet MLW and had a 12.5 hour period. Figure 2a shows the extent of inundations at high and low water. Of the

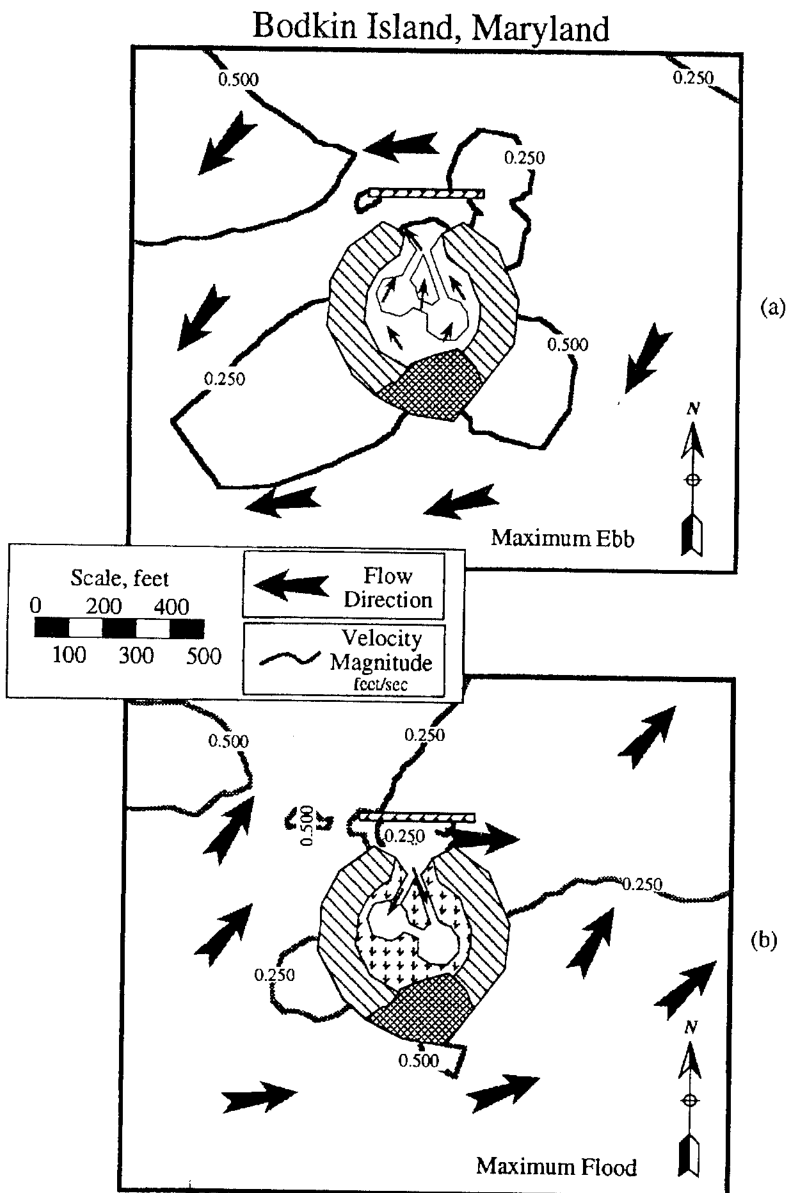

Figure 1. Bodkin Island, Eastern Bay, Maryland

Figure 1. Bodkin Island, Eastern Bay, Maryland

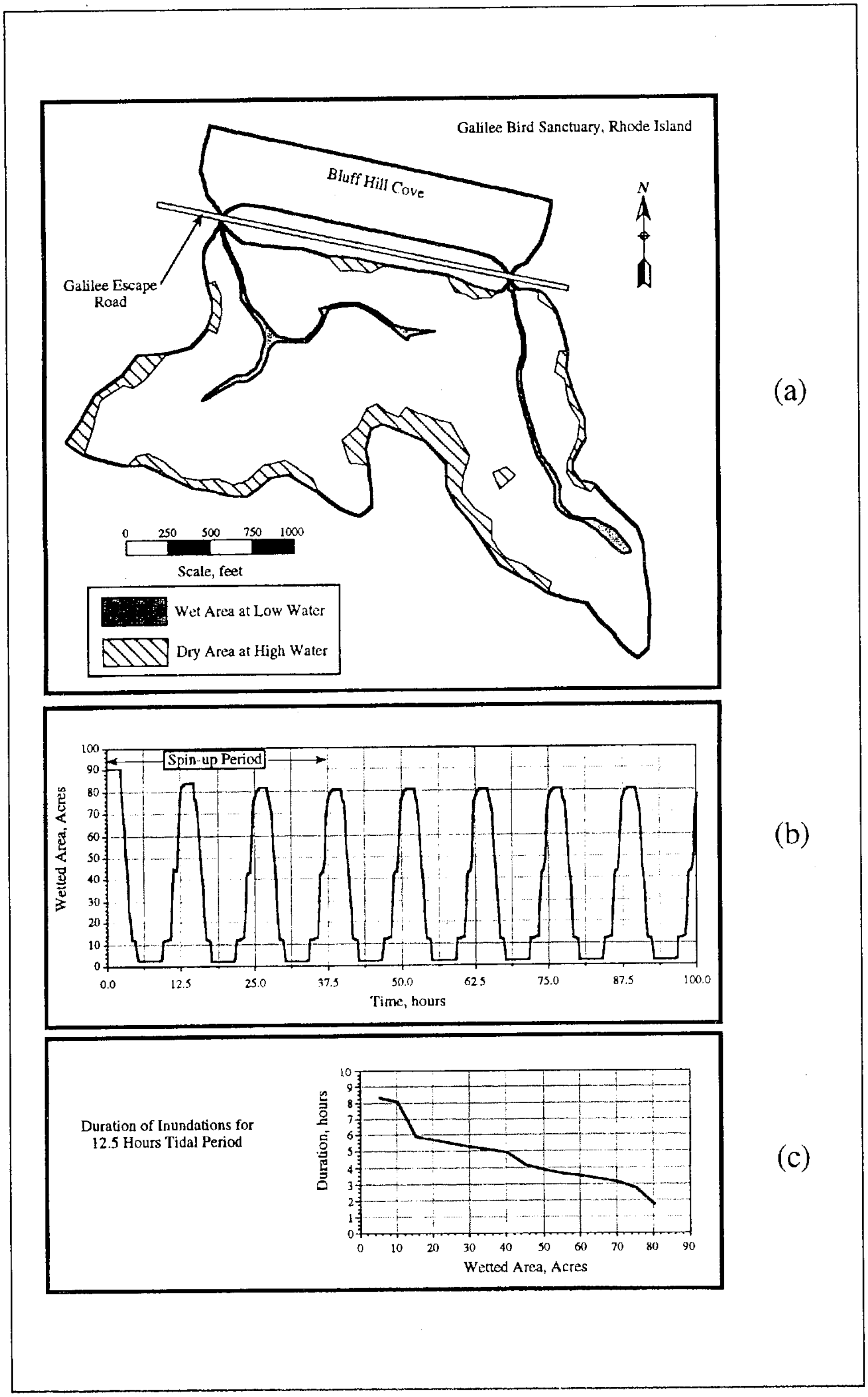

Figure 2. Galilee Bird Sanctuary, Rhode Island

90 acres south of the Galilee Escape Road, approximately 81 acres reweds during each tidal period with the box culverts in place (Figure 2b). Using the data generated by RMA-2, the extent and duration of inundation can be determined (Figure 2c). This information is used by biologists to determine the amount of beneficial wetland area resulting from this plan.

The results of this study indicate that two 8'x10' box culverts installed at both ends of the Galilee Bird Sanctuary allow maximum inundation with out causing excessive channel scour. Control gates will be needed only during severe storms because the normal tide range does not cause flooding of adjacent property. The regions in which *Phragmites australis* will be eradicated can be predicted using data from this study.

Conclusions

This paper shows that the hydrodynamic model RMA-2 used in conjunction with the FastTABS graphical interface provides a useful tool for the planning of wetland restoration and enhancement. The simulations can be done quickly and efficiently, resulting in a cost savings during the design phase which can be applied toward wetland construction and enhancement.

Acknowledgements

The tests described and the resulting data presented herein, unless otherwise noted, were obtained from research conducted under the Wetlands Research Program of the United States Army Corps of Engineers by the Waterways Experiment Station. Permission was granted by the Chief of Engineers to publish this information.

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Hydrology, Vegetation, and Nutrient Removal Dynamics in a Large Constructed Wetland, David L. Sites, Ph.D, Jonathon Polinkas, Vickie Schwencke, P.E., St. Johns River Water Management District, Palatka, FL

Abstract

A 560 acre constructed wetland in Central Florida is being operated as an experimental project to develop system design and management plans for 3,500 acre treatment marsh to remove solids and nutrients from polluted lake water. The demonstration project, constructed on a site that was marsh prior to being drained for vegetable farming, consists of two cells approximately 1.0 x 0.25 miles each, with flow parallel to the long axis of each cell. The marshes are shallow (1-2 feet), are dominated by *Typha latifolia* (cattail), and the vegetation dynamics and water quality in the first cell (180 acres) showed that increasing vegetation density (as measured by stem counts) was parallelled by a significant increase in the hydraulic grade line between the inflow and outflow points. Solids and phosphorus removal efficiency, however, did not change over the period. Total suspended solids removal over the period ranged between 85% and 95%, and phosphorus removal averaged 30 - 40%. A rhodamine-B dye study was performed to evaluate residence time and flow patterns. Flow was extremely complex, with the most rapid dye passage associated with a few remaining farm ditches oriented parallel to the flow direction. analysis of data collected after the accidental introduction of an hydraulic short circuit suggested that (1) suspended solids and phosphorus removal occur sequentially, not simultaneously along the flow path, (2) flow may channelize into areas of lesser plant density within the marsh as well as in the remaining farm ditches. In the near future, we will be further evaluating the relationship of plant density, hydrology and nutrient removal by increasing inflow rates.

(Paper not provided)

Stormwater Best Management Practices and Wetlands Restoration, John N. Hochheimer,[1] Mary Beth Corrigan,[1] Fran Eargle[2]

Introduction

Although wetlands have long been recognized for their flood control and water quality improvement functions, there is increasing concern that unrestricted use of natural wetlands as receiving waters for point and nonpoint sources of pollution, such as urban stormwater, will have an adverse effect on wetlands and wetland biota. Natural wetlands, because of their position in the landscape, are often the receivers of stormwater, either inadvertently or by design. Impacts to the wetlands (through changes in hydrology and/or water quality) can occur, and best management practices (BMPs) need to be designed to minimize these impacts. Stormwater BMPs can potentially impact downstream wetlands and this must be considered when designing stormwater treatment systems. Management practices can be designed to preserve existing wetlands in a watershed so that they can continue to provide multi-function characteristics and/or to restore degraded wetlands. With proper planning, many wetlands degraded by stormwater runoff can be restored by using appropriate BMPs. This paper outlines some of the factors to consider when selecting BMPs to restore wetland functions and presents some ways to reduce the impacts of stormwater on wetlands.

Factors to Consider When Selecting BMPs

Best management practices are used to protect natural wetlands from the impacts of stormwater, including changes in wetland hydrology or water quality. If natural wetlands are used as a part of a stormwater treatment system (as a final polishing step), BMPs can pretreat runoff that may potentially impact the receiving natural wetland. BMPs must be selected to carefully consider the combination of variables that influence a wetland and the variables that characterize stormwater runoff entering that particular wetland. Wetland factors to consider include wetland type, hydrology, existing site-specific conditions, and climatic conditions. Stormwater factors include quantity and quality of runoff and the frequency of runoff events.

Wetland factors

The chemical and physical characteristics of natural wetlands can vary widely depending on the climate and geology of the region, hydrology, landscape position, and biotic influences. Wetlands are part of a watershed; their

[1] Tetra Tech, Inc., Fairfax, VA.
[2] U.S. Environmental Protection Agency, Washington, DC.

position in the landscape is influenced by and influences the other characteristics of a watershed. Management of wetland resources should be addressed on a landscape or watershed scale. Knowledge of site-specific conditions is important to understand the impacts certain management decisions have on an individual wetland. Understanding the interactions of a particular wetland with the other watershed features provides a broader and more comprehensive perspective of impacts of various management activities on a particular wetland and the watershed as a whole. For example, by changing the hydrology in a wetland, the water retention and sediment attenuation functions may be lost, resulting in downstream hydrological and water quality impacts; or vegetative species and composition may change, resulting in habitat quality changes.

Wetland Type. The effects of stormwater on a particular wetland depends, in part, on the type of wetland in question (e.g., bottomland hardwood, prairie pothole, etc.). Wetland type can be defined as the combination of attributes (e.g., water source, hydrology, soils, or predominant vegetation) that make a particular wetland type different from other wetland types. The classification developed by Cowardin and others (1979) breaks wetlands into systems, subsystems, and classes analogous to plant or animal taxonomic classifications.

Hydrology. Mitsch and Gosselink (1986) describe hydrology as probably the most important factor in establishing and maintaining specific types of wetlands and wetland processes. Precipitation, surface water inflow and outflow, groundwater exchange, and evapotranspiration are the major factors influencing the hydrology of most wetlands. Each wetland type exhibits a unique hydroperiod (periodic or regular occurrence of flooding and/or saturated soil conditions) that is fundamental in the stability of a wetland system. Hydroperiod is a function of the water budget and storage capacity for a particular wetland (Mitsch and Gosselink, 1986). Since wetlands typically represent a transition from terrestrial to open water ecosystems, the effects of changed hydrology are extremely variable. Hydrologic disturbance of a wetland may cause a shift from a function as a sink for nutrients and metals toward a function as a source of these materials, impacting downstream communities (Brinson, 1988). Hydrologic conditions affect many abiotic factors, including salinity, soil anoxia, and nutrient availability, as well as biotic factors such as the wetland flora and fauna. The biotic factors can also affect wetland hydrology, for example evapotranspiration by plants or impoundments created by beavers.

Climate. The amount and seasonal distribution of rainfall can play an important role in determining characteristics of a wetland such as the species composition, soil characteristic, and ecological functioning of inland wetlands. Conversely, changes in the hydrologic regime of a wetland can cause changes in the character of wetland ecosystems. Factors such as precipitation patterns, including the frequency, intensity, and duration of storm events, determine the quantity and timing of runoff (Hammer, 1992). Other climatic factors, such as temperature, wind, relative humidity, and incident solar radiation, also affect wetlands.

Site-Specific Conditions. Wetlands in undeveloped areas may be relatively pristine or they may be impacted by agricultural activities, particularly sedimentation and drainage. Wetlands in developed urban areas may be impacted due to changes in surface water and groundwater hydrology or water quality. Wetland plant communities may be altered as a result of hydrologic or physical disturbances; and exotic or invasive plant species, which become established more easily in disturbed ecosystems, may be present, affecting the habitat functions of the wetland. Also, natural buffer areas surrounding some wetlands may have been eliminated, lowering the diversity of the wetland system and reducing areas for wildlife use. However, wetlands in pristine areas may contain habitat for fisheries or endangered species. These site-specific conditions are important when selecting specific BMPs or other stormwater management strategies.

Stormwater factors

Stormwater Quantity. Changes in land use affect the quantity of stormwater runoff in a watershed. For example, urbanizing watersheds are characterized by increases in impervious surfaces, such as roads, sidewalks, parking lots, and buildings. Increased impervious areas lead to increased runoff volumes and velocities. Additionally, natural stormwater conveyances (e.g., streams or gullies) tend to be replaced with hard structures such as concrete gutters or scales because of the increases in erosion that often accompany increased runoff quantities and velocities. Watershed changes modify the established rainfall-runoff relationship that exists in a watershed. The most common effects are reduced infiltration and decreased travel time, which significantly increase peak discharges and runoff volume (USDA-SCS, 1986). This may result in stormwater pulses of greater magnitude and changed duration entering wetlands instead of sheet flow or constant baseflow.

Frequency and Intensity of Storm Events. Storm frequency refers to the time between rainfall events (return periods) of equal intensity. Storm intensity is typically defined as a volume of rain in a given time period. The frequency and intensity of storm events vary regionally and seasonally. For example, storm events in the central and southwestern United States typically occur less frequently than those in the east, but may occasionally produce large volumes of runoff. Some areas may receive the bulk of their annual precipitation as snowfall, and snowmelt would be a major contributor to streamflow and runoff in such regions.

Stormwater Quality. Wetlands may be impacted by increased loadings of pollutants in runoff. For example, the principal types of pollutants found in urban runoff include sediment, BOD, COD, nutrients (phosphorus and nitrogen), heavy metals, pesticides, bacteria, viruses, hydrocarbons, increased temperature, and trash or debris (USEPA, 1983). The levels of nutrients in stormwater may vary according to season and land use in a watershed. Phosphorus is primarily transported bound to sediments, while nitrogen is often a dissolved pollutant. The source of sediments in stormwater may be erosion of

bare soil in the watershed or channel scouring due to increased stormwater volumes and velocities. Some wetland types, such as tidal and riverine wetlands, may benefit from settling of some sediments and particulates, while other wetland types may be adversely impacted by low sediment loadings. The results from the Nationwide Urban Runoff Program (USEPA, 1983) were relatively uniform across the United States, but varied over a wide range, which supports the need for collection of site-specific data prior to making critical water quality management decisions (Urbonas and Stahre, 1993).

Measures for Reducing Impacts of Urban Stormwater Runoff on Wetlands

Since many wetlands have been impacted by changes in stormwater runoff, particularly from urbanization, restoration plans may require measures to reduce the impacts of stormwater runoff. A variety of BMPs (e.g., vegetated filter strips, detention ponds, retention ponds, infiltration devices, etc.) can be used to lessen stormwater runoff impacts. However, selection and design of stormwater best management practices (BMPs) necessary to minimize the impacts of changes in land use and associated increases in stormwater runoff should consider the site-specific features of the wetland as well as the relationships of the wetland within a watershed. Additionally, the impacts of a particular BMP need to be considered both locally in relation to an individual wetland and within the watershed to determine potential impacts to other resources.

Pretreatment of stormwater

The level of treatment needed to restore a wetland that receives stormwater runoff depends on the type and condition of the wetland; on the quality, quantity, and distribution of runoff; and on what levels of impacts to the wetland are acceptable. Ideally, all pollutants and sediments not present in runoff prior to watershed development should be removed before discharge to wetlands. For example, excess sedimentation in wetlands can result in the alteration of bottom morphology, hydrologic function changes, and shifts in animal and plant communities. Sediment also serves as a primary transport mechanism for pollutants through absorption and adsorption, particularly phosphorus. Removal of excess sediment (to predevelopment levels) from stormwater can be done with structural methods (e.g., forebays or sediment basins) or potentially less-costly nonstructural methods (e.g., pollution prevention programs or street sweeping). Some regions, such as southern Florida and the southwest, possess soils with high infiltration rates, and a major concern relating to urban stormwater may be the potential contamination of ground water. Instituting stormwater pretreatment may be part of a larger effort to restore wetland and downstream ecosystems and may involve analysis of stormwater dynamics at the watershed level and a variety of actions aimed at runoff quality maintenance or enhancement.

Matching wetland characteristics to BMP design

Wetlands should be characterized with a classification system such as that of Cowardin and others (1979), advanced identification, or state wetland conservation plans prior to introducing additional stormwater or modifying the characteristics of existing stormwater inflows with best management practices. The existing functions of a wetland should be used to determine the type and placement of BMPs. In addition to considering general classification characteristics, site-specific evaluations of wetlands should be made. The modification of existing stormwater characteristics due to development or the type of BMPs used should be compatible with the wetland type and watershed characteristics to protect existing functions of wetlands systems. For example, sediment traps should be used prior to discharge into wetlands that have known sensitivity to increases in sediment loadings.

Hydrology

Both the quantity and quality of stormwater runoff are significantly affected by watershed development. Increased impervious area, removal of trees and other vegetation, and soil compaction in a watershed can increase runoff volume (Schueler, 1987), altering the natural hydroperiod of receiving wetlands. Reduced infiltration of stormwater may reduce baseflow and alter the groundwater hydrology of some wetlands. Known hydrologic impacts to wetlands associated with increased stormwater runoff include changes in wetland response time, changes in water levels in the wetland, and changes in the detention time of the wetland. Increased runoff volumes are also associated with greater water level fluctuations in receiving wetlands, which may adversely affect wetland plant and animal communities (Azous, 1991). Large inflows of water into a wetland may cause disturbance through changes in circulation and flushing characteristics and through possible erosion of wetland soils.

The natural hydrologic characteristics of a wetland should be one goal of the design of stormwater management systems. Where possible, the existing hydroperiod of natural wetlands should be maintained. In arid areas, one source of water to recharge wetlands may be stormwater. In these areas, BMPs may provide a role in enhancing wetland ecosystems through restoration of a more natural hydroperiod. The source of water in a wetland is also important in designing a stormwater management system. In wetlands where the source of water is primarily in the form of surface runoff, the use of BMPs that incorporate infiltration into the soil as the method for stormwater treatment may change the natural hydroperiod of adjacent or downstream wetlands. As mentioned, changes in the natural hydrologic characteristics can adversely affect the structure and functions of these wetlands. The use of stormwater systems that treat stormwater by temporary detention or retention before discharging into a natural wetland, when properly designed, may help to restore the predevelopment hydrologic conditions in the of wetland. Conversely, the use of detention or retention systems adjacent to or upstream of groundwater

wetlands may adversely affect their hydroperiod by altering natural baseflow conditions.

Climate

Local climatic conditions determine the quantity, frequency, and intensity of stormwater runoff events. Under natural conditions, wetland characteristics are influenced by climatic conditions and other environmental characteristics. The placement of BMPs to treat stormwater or to protect existing wetlands from stormwater impacts may actually harm the systems if the practices are not designed based on the local conditions and the natural wetland characteristics. The BMP type and design should be based on both design storm requirements and adjacent wetland characteristics.

Water quality

Natural nutrient levels within a particular wetland vary widely among wetland types, and the potential effects of loadings from stormwater runoff must be evaluated with consideration of the type of receiving wetland when considering BMPs. Wetlands may vary in their ability to absorb or transform these compounds, due to variations in their hydrologic, soil, and vegetative characteristics, and may be only temporary sinks for some compounds. While nitrogen may be removed from wetland soils as nitrogen gas through the process of denitrification, phosphorus may be held in wetland soils until a wetland's natural storage capacity is reached, beyond which it may no longer function as a sink or may even become a net exporter of phosphorus to receiving waters (Richardson, 1989). Pretreatment of stormwater flow prior to its inflow into existing wetlands can help in attenuating fluctuations in nutrient levels.

The pretreatment of stormwater through the incorporation of BMPs may also reduce the amount of sediments that enters a wetland. If incoming sediment loads are high, the wetland's storage capacity may be reduced over time and its ability to function may be affected. While the increased loading of sediment to wetlands associated with stormwater can adversely affect their functional characteristics, the removal of most or all suspended particulates through the placement of BMPs can also result in wetland degradation. Reductions in the natural levels of sediment deposition in a wetland can result in the embedding of downstream substrates in some wetland types or in erosion in other types and potentially in erosion and channel scouring in associated downstream systems. In some systems the resuspension of downstream floodplain sediments may occur. Natural soil and sediment conditions should be considered in a wetland or wetland system when determining the feasibility, design, and type of BMPs to be used.

Summary

Best management practices may be used to treat or pretreat stormwater runoff as part of a wetlands restoration program. Many factors need to be considered when restoring a wetland, including treatment of the quantity and quality of stormwater runoff resulting from changes in land use within a watershed. BMPs, when properly designed and implemented, offer one component of a wetlands restoration program to restore wetland functions to degraded natural wetlands and to protect existing multi-functions of natural wetlands.

Disclaimer

The views and opinions expressed in this article are those of the authors and do not necessarily reflect the policies of the U.S. Environmental Protection Agency.

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Relationships Between Plant Communities, Microtopography, and Hydrology and Implications for Swamp Restoration and Creation, Ted Shear and Brian Bledsoe, Visiting Lecturer and Graduate Research Assistant, respectively, Restoration Ecology Program, Dept. of Forestry, North Carolina State University, Raleigh, NC

Introduction

Current swamp restoration techniques often fail to establish the desired plant community, due in part to a lack of basic knowledge about wetland structure. Factors that influence the composition of plant communities in southeastern coastal plain swamps are extremely complex and difficult to quantify. The floodplain environment fluctuates between favorable edaphic and climatic conditions for plant growth with low water levels and the severities of anaerobiosis during flooding. Topographic heterogeneity on the scale of individual plants, or microtopography, creates a complex mosaic of microsites with substrates that differ structurally, hydrologically, and chemically. Species are distributed along gradients associated with varying topographic, hydrologic, and edaphic factors.

Some Factors Controlling Swamp Forest Community Composition

Slight variations in elevation, soil texture, and soil structure have pronounced effects on moisture, aeration, and the frequency and magnitude of flooding (Robertson et al. 1978; Wharton et al. 1982). Microtopography, flow distribution and velocity, and associated soil chemical and physical properties influence the distribution and diversity of plants by providing a variety of sites favorable for seed germination and establishment of different species (Harper et al. 1965).

Seed dispersal, germination, and seedling development are partially governed by the frequency, duration, flow characteristics, temperature, and aeration of flood waters. Seedlings are more sensitive to inundation than to soil saturation, especially if the foliage is submerged. Damage to seedlings by inundation during the growing season, even for short periods, can be severe (Harms 1973; Kozlowski 1984). In a South Carolina swamp, the major cause of mortality of baldcypress (*Taxodium distichum*) and water tupelo (*Nyssa aquatica*) seedlings was a summer flood (Sharitz et al. 1985). In an Ohio floodplain swamp, topographic heterogeneity created gradients in soil texture, nutrients, and water holding capacity, resulting in more herbs where litter and debris collected than in scoured depressions (Hardin and Wistendahl 1983). Seedlings were distributed non-randomly across 16 different microsite types in

a South Carolina swamp forest (Huenneke and Sharitz 1986). Tree seedling distribution appeared to be strongly influenced by the permanence and stability of microsites. Similar patterns were observed in a bottomland hardwood forest in Florida (Titus 1990). Slight differences in the depth of the water table can resul in significant differences in herbaceous and woody vegetation (Wistendahl 1958; Bell 1974a & b; and many others).

Availability of soil nutrients changes under flooding. The effects of these changes on plant productivity are difficult to predict due to interactions between nutrients, organic matter, dissolved oxygen, and plant hormone responses. The difference between oxygen diffusion rates and the demand for oxygen by soil microorganisms makes it apparent that reduced conditions will prevail in flooded soils. The rate and degree of reduction are influenced by various soil parameters including oxygen concentration, E_h, pH, organic matter, and temperature (Ponnamperuma 1984). There are complex interactions between hydrologic regimes and soil physical and chemical properties that create a variety of soil environments within a swamp forest. Elevation alone does not adequately represent the "site inundation, soil drainage-aeration complex" gradient (Robertson et al. 1978).

Analysis of Small Stream Swamps in Eastern North Carolina

Methods. We analyzed the vegetation of two swamp forests along Durham Creek in Beaufort County, N.C. For convenience, they are called the upstream stand and the downstream stand. Regression relationships between the two sites and a nearby gaging station were used to hindcast 25 years of surface flooding regimes. Elevations of individual plant microsites were used in conjunction with stage probabilities to examine individual species responses to varying flooding regimes. Soil characteristics were described, including: texture; depth to the least permeable horizon; the depth to, abundance, and Munsell color of distinct mottling; and the color and thickness of each horizon. A comprehensive view of the plant community-environmental complex was developed with two multivariate ordination techniques - Detrended Correspondence Analysis (DCA) and Canonical Correspondence Analysis (CCA). Complete descriptions can be found in Bledsoe (1993).

Hydrology. Water table fluctuations in the two study stands were closely related. The magnitude of flooding in each site was strongly affected by antecedent moisture conditions. The hydrograph for the downstream stand indicated a flooding depth considerably greater than in upstream stand during the growing season. This difference was no longer apparent in flooding events after October (Figure 1). The upstream forest depleted soil water more rapidly because of greater transpiration and was subject to more extreme fluctuations in the water table during the growing season.

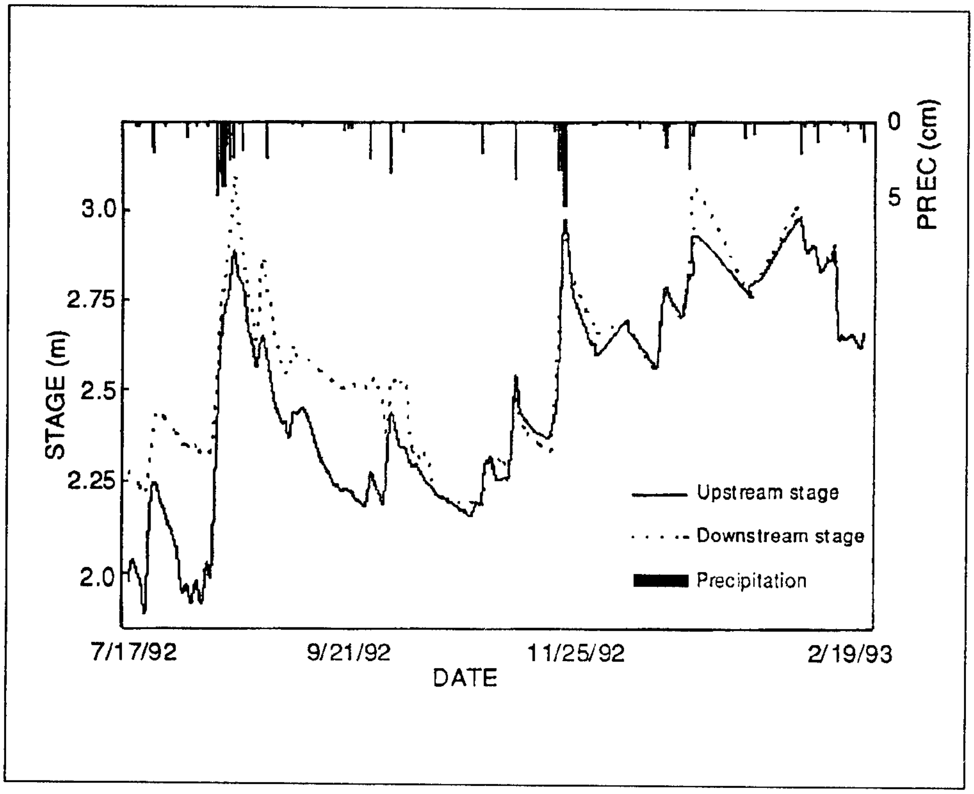

Figure 1. Stage relationship of the two study sites

Vegetational Characteristics. The stands are similar in the occurrence and total number of species, but structural differences are considerable. Plots in the upstream and downstream stands contained 74 and 76 species of vascular plants respectively. The upstream stand is dominated by swamp tupelo (*Nyssa sylvatica* var. *biflora)* with red maple (*Acer rubrum*) and sweetgum (*Liquidambar styraciflua*) as major associates. The dominant tree species in the downstream stand is red maple, which occurs abundantly in all sizes. Baldcypress dominates the wettest areas, and swamp tupelo is important on all but the wettest substrates. Green ash (*Fraxinus pennsylvanica*) only achieves canopy dominance in small areas of the downstream stand. Water tupelo is unique to the downstream stand, occurring only along the stream channel. The shrub-sapling stratum is much more prominent in the upstream stand with relatively high densities of *Ilex opaca*, *Clethra alnifolia*, and *Persea borbonia*. In the more open understory of the downstream stand, *Fraxinus caroliniana*, *Ilex opaca*, *Persea borbonia*, and *Symplocos tinctoria* are the dominant sub-canopy species. Red maple and sweetgum saplings are abundant in both sites and represent most of the regeneration of canopy species. The ground layer of the upstream stand is dominated by *Leucothoe axillaris* with mosses, *Woodwardia areolata*, and *Saururus cernuus* increasingly abundant with decreasing elevation. *Woodwardia areolata* and *Saururus cernuus* are the most abundant species in the ground layer of the downstream stand.

Soils. Varying amounts of exchangeable calcium, magnesium, and acidity were the most obvious differences in soil chemical properties between the sites. There were significantly greater amounts of calcium and magnesium in the soil of the downstream stand. This is perhaps due to less leaching than occurs upstream where there are larger fluctuations in the water table. The clay fraction was higher at lower elevations in both sites.

Relationships Between Environmental Factors and Plant Community Composition. Elevation accounted for much more of the variation in species composition in the downstream stand than in the upstream stand. The elevational distribution of seedlings and saplings of most trees conformed to the distribution of canopy members, suggesting that the environmental gradient separates populations of species in the early stages of life. Some species indicated a broad tolerance while baldcypress occurred in a very narrow range of elevations. Tree species elevations were more variable in the upstream site. Distributions of species within elevational increments reflect a variety of individualistic responses to differing hydrologic and edaphic gradients associated with elevation in the two stands.

The DCA revealed that a combination of hydrologic and soil fertility factors were the best predictors of species occurrence and community composition. These included soil % base saturation, soil acidity, and three different expressions of the flooding regime: elevation, flooding frequency in the growing season, and depth to distinct mottling. Cluster analyses were used to delineate community types and environmental segments (Figure 2). Pronounced differences in flooding regime and soil fertility appeared to influence the dominant species occurrence with green ash only attaining dominance in a narrow range of flooding frequencies and at relatively high base saturation. Although red maple and sweet gum commonly occur together throughout the forests, they only appear as codominants at or beyond the upper limit of growing season surface flooding. The CCA supported and extended the interpretation of the flooding-fertility gradient. Species such as baldcypress and *Fraxinus* spp. which dominate the wetter end of the gradient were closely related to % base saturation and depth to mottling, which reached extremes in the downstream stand. Swamp tupelo was associated with the relatively high acidity of the upstream bottom.

These results point to the dual importance of soil moisture and fertility. Soil fertility of a frequently flooded site is inseparable from its hydrologic regime due to interaction between the soil aeration-drainage complex and the availability of chemical species within the soil. It is difficult to surmise which factors play the most critical roles in determining the response of plant species. Depth to mottling, flooding frequency, elevation, and several soil chemical properties were all significantly correlated. Subtle differences in flooding regimes and soil fertility have created differences in species responses between the two forests.

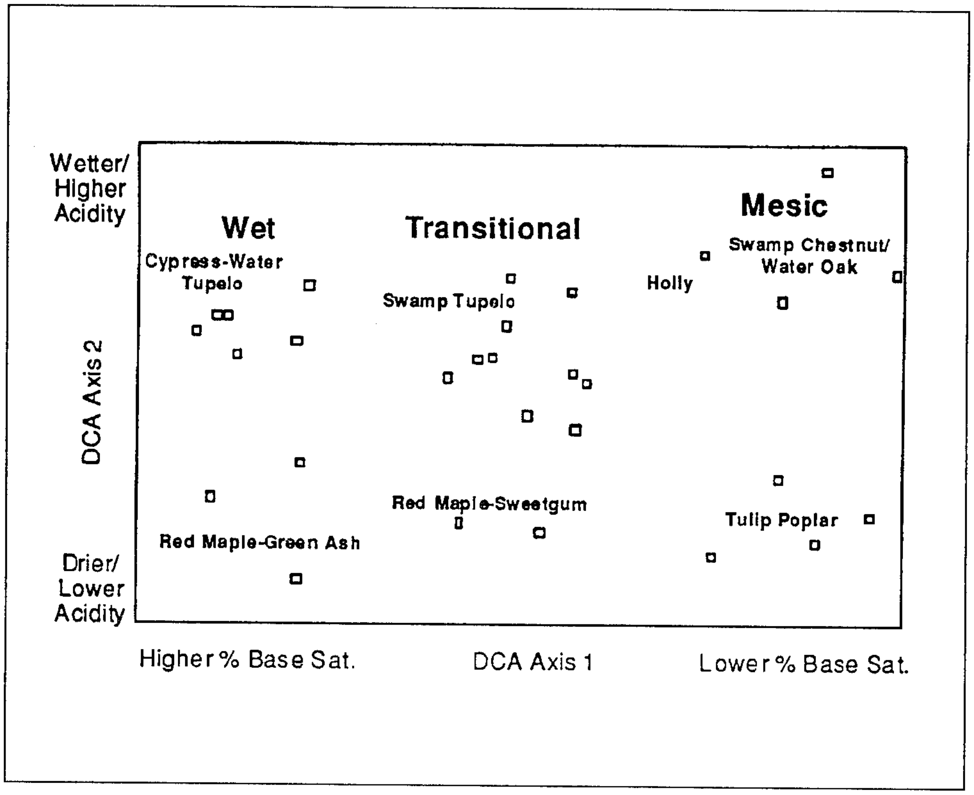

Figure 2. Community types delineated in the two swamp forests.

Implications for Restoration and Creation of Swamp Forests

The goal of any wetland forest restoration or creation project should be to create an accurate, persistent representation of a particular forest type (exceptions are artificial systems such as water-supply impoundments and green-tree reservoirs). We offer the following observations and suggestions:

The wetland axiom HYDROLOGY IS EVERYTHING is wrong. HYDROLOGY IS CRITICAL but it interacts with other factors to determine wetland structure and function. **Most hydrologic models of wetlands do not accurately describe the natural wetland system** and are too limited to be useful. Most attempts to quantify the hydrologic regimes influencing floodplain forest vegetation have concentrated on surface flooding. The hydroperiod is extremely variable and the hydrodynamics of these systems primarily occur below the soil surface (Day and Megonigal 1993).

Plant communities can change quickly across gradients of elevation and soils. This makes prediction of the ultimate persistent plant community difficult and complicates the selection of plant material, particularly when microtopography is introduced. **Any grading of the restoration site must be precise.** In our study, an elevational difference of 15 cm represented a difference of 30% in surface flooding frequency, and probably had similar

dramatic effects on the subsurface moisture. **The wetland forest floor is quite variable in elevation and soil properties.** On sites where this variation has been destroyed (farm fields, excavations, etc.), creation of microtopography could potentially improve recruitment by providing a variety of sites favorable for seed germination and establishment of different plant species. **Sites with very similar flooding regimes and soils often have different successional trajectories (i.e., different plant communities).** The stands in our study are on the same stream with soils in the same series and are similar in age, yet they are rather different. Which would be the better reference ecosystem? Perhaps it would be better to use both stands and maybe even add additional stands to establish a range of successional trajectories for such systems in the region. **When planting seedlings to obtain a specific community composition, it may be necessary to limit flooding in the early years.** This requires water control structures that can be easily adjusted and diligent monitoring to avoid extended periods of inundation.

Consideration of these factors is difficult and expensive at best, but necessary for development of specific wetland ecosystems. When resources are limited, perhaps the best strategy toward swamp forest rehabilitation is to provide, to the extent possible, the appropriate soil chemical and hydrologic conditions along with seed source and possibly some planted individuals from local sources which have appropriate physiological and competitive abilities for the place in question. In other words, provide the best site possible, provide accessibility, and walk away without expecting a specific result.

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Meeting Technical Needs for Wetland Vegetation Restoration: Increasing Wetland Diversity, Mary M. Davis, Ph.D., U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS

Wetland restoration, establishment, and management (REM) efforts have become increasingly important in developing landscapes across the country, particularly since the implementation of federal wetland regulatory legislation in the mid-1970's. Increased recognition of wetland values has led to programs that require mitigation for unavoidable loss of wetland functions and encourage restoration of converted wetlands in agricultural lands. As a result there is a great demand for information about wetland restoration techniques that help achieve project objectives and improve restoration success rates as economically as possible. This includes the need to establish diverse wetland vegetation that are similar to natural systems on both landscape and site-specific levels.

Establishment of wetland vegetation in REM projects requires the successful placement of plants within species tolerance limits. Species limits are determined by complex interactions among hydrologic, physical, chemical, and biotic components of the system. This is difficult, and efforts to establish vegetation in wetland REM projects often fail (Kusler and Kentula 1990). In addition, there is limited species-specific information on wetland vegetation handling, planting, and management requirements (Marburger 1993). As a consequence, a limited number of plant species are successfully established in wetland REM projects at the expense of diversity on site.

Improved Wetland Diversity

Diverse wetland vegetation is generally desirable in REM projects because establishment is likely to be more successful than less complex systems. This is true for a variety of reasons. On a site level, increased numbers of species means an array of environmental tolerances is represented. As the new wetland experiences fluctuations in various environmental conditions over time, such as water level, temperature, and herbivore, some plants will not survive. If the project is dominated by a few species, there is a possibility that the project will fail with the death of only one species. It is not possible to plan for all eventualities, but it is possible to "hedge your bet" by planting a variety of species. Establishment of a variety of desirable species will increase competition for resources and limit the potential for aggressive species to overtake a project site. In addition, plant species and structural complexity of natural ecosystems generally correlate with wildlife species richness, particularly for birds (Weins 1989).

Diversity of wetland types within a landscape increases wildlife value of an area by providing required habitats for different life history phases of animals, such as feeding, winter cover, and breeding (Heitmeyer et al. 1984, Frazer

et al. 1990). Further, as fully functioning components of a landscape, a variety of wetlands in an area enables an exchange of individuals among neighboring populations. Migration among populations helps maintain genetic diversity and repopulation of local extinctions.

The definition of optimal diversity is a matter for discussion. In-kind wetland replacement requirements assume that the natural landscape has optimal diversity by virtue of natural developmental processes and the adaptation of organisms to those conditions. This may often be the case, however, disturbed landscapes, such as urban or mined areas, require a different approach. Proper siting and design of wetland REM projects can contribute diversity to a landscape for improved wildlife value through manipulations of hydrological conditions, and maintenance of early successional vegetation (e.g., Garbish 1986, Marble 1990). Once project objectives are determined, diversity at the landscape and site levels can be affected in the wetland REM project design and implementation phases. It should be noted that all wetland REM project actions may be subject to regulatory agency review prior to implementation. Ways to increase wetland REM project diversity are discussed below.

Project design

Diversity of a system is a function of the number of types in the system and how evenly those types are distributed. A diverse community, for instance, has a large number of species that are evenly distributed, that is there is no dominant species. A landscape can be described as having low diversity if there is mainly one forest cover type or landuse interspersed with a few small areas of different types. Wetland REM project diversity can be optimized in the planning phase by considering the types and distributions of wetlands in the surrounding landscape and of organisms within the wetland site.

On the landscape level, given project constraints, the project planners can choose to replace wetlands in-kind or increase diversity by altering conditions to create new wetland community types. For example, hydrology or surface elevations can be altered to create more or less aquatic habitat. Dominant vegetation can be shifted to herbaceous or woody species. Wildlife diversity can be increased with the development of natural, protected corridors that facilitate movement of animals among different habitat areas. It should not be overlooked that movement of seeds by animals and water from natural areas into project areas along vegetation or hydrological corridors is a natural mechanism to help maintain plant diversity.

A diverse wetland has a rich assemblage of plant species distributed across moisture gradients. The ground surface configuration determines the extent and arrangement of moisture zones. Diversity is maximized by creating a wetland with a variety of moisture zones that have convoluted and interdigitizing edges. Wildlife benefits as well when the ratio of edge distance to habitat area is large.

Wetland plant species characteristically occupy zones that differ in hydrologic regime. Within each zone, individuals are typically interspersed randomly among species or located in small clusters of species. Different types of zones can be diversified in a wetland REM project by selecting varieties of species that differ in structure (herb, shrub, or tree). When designing planting schemes, attention should be paid to arrange the plant species in patterns similar to natural systems rather than straight, conveniently planted rows. In addition, species should be planted above and below the elevation band where the target moisture zone is expected to be located; this allows for species survival under a variety of hydrological conditions.

Project implementation

Opportunities exist at several phases of wetland REM projects implementation to optimize diversity, primarily on the site level. There are limitations, however, such as the lack of commercially available diverse plant material. In addition, short time periods of project involvement discourage planting additional species as the relatively harsh site conditions ameliorate with project development. Some of these opportunities and limitations are discussed below.

Species selection. Standard guidance for species selections is to use locally occurring species that tolerate planned site conditions and meet project objectives. If maximizing species diversity is a project objective, selection of species within a moisture zone should include consideration of plant form, mode of reproduction, and stratum. In marshes, herbaceous plant forms need to be compatible. For example, a tight sod forming grass species may inhibit growth and reproduction of slower growing or single-stemmed species. If maximizing structural diversity is the priority, then herbaceous and midstory tree species should comprise the majority of species as in natural swamps. These can be planted in addition to the more commonly used canopy species (Clewell and Lea 1990). Forest midstory and groundcover species are often shade tolerant species, and attention may be required to the provision of nurse plants to ameliorate initially harsh site conditions (see below).

Plant source and acquisition. Wetland plant material is acquired from natural sites and from commercial sources. Seeds and vegetative propagules collected from local natural wetlands are likely to be tolerant of regional conditions and have the genetic diversity necessary to adjust to changing climatic conditions. Collection of plant materials from natural areas is limited by the degree of site disturbance. Seeds can be collected with little impact, but digging of vegetative propagules is not advisable unless the site is going to be developed. It is desirable, therefore, to have as great a diversity of commercially available plant material as possible.

The most important factors that restrict supply of diverse plant materials from commercial nurseries are a lack of demand and limited knowledge about species handling requirements. These factors are interrelated, and so must be addressed together. Demand for diverse plant material needs to be increased

by wetland REM project managers who are aware of the advantages of using such material. Specific efforts need to be made to gather plant species information from the scattered sources into readily available guidance. Much information on handling common species simply does not exist. Species-specific experience is required for plant propagation, handling, establishment, and management techniques.

Planting methods. An effective means of actively obtaining natural species diversity in a wetlands REM project is to move topsoil containing seeds and vegetative propagules from a natural wetland to the wetland project site. Topsoil can be moved with the plants intact, either as sod or in smaller plugs. Successful marshes have been created by using the topsoil as a mulch and spreading it over a contoured ground surface. Caution needs to taken, however, that stockpiling time is minimized and that stockpiles are not placed in wetlands (Garbish 1986). In addition, careful matching of hydrological conditions between topsoil donor areas and recipient areas facilitates the formation of vegetation zones in the project area. Use of topsoil from natural wetlands is limited to cases where the donor wetland will be developed. Precautions should be taken that potential nuisance species in the seedbank are not transferred to the project site. Species composition of the seedbank can be determined by identifying seedlings that emerge from topsoil samples.

Planting schedule. Certain plants, primarily shade-tolerant species, grow best in the low-light and cooler interiors of swamps. These species survive and grow best when protected from harsh conditions that are commonly found in wetland REM projects. These plants require the presence of hardier plants that may provide shade, protection from wind, or improved soil fertility. These cover or nurse crops can be planted at the same time or prior to the establishment of less tolerant species. Interplanting species after the establishment of an initial complement of plants prolongs the involvement period with the project, but greatly increases the potential for using species not commonly used in wetland REM projects.

Site preparation. Species diversity in natural wetlands is greater where the surface is uneven. Hummocks, fallen logs, and depressions provide a variety of hydrological conditions which are exploited by many species. For example, a plant growing on a hummock can escape long periods of inundation like it would experience directly on the wetland floor. Creation of a rough surface in a wetland REM project does not look "neat," but it does help add a feature found in natural areas.

Conclusions

There are many ways in which wetland diversity can be affected at different stages of wetland restoration and establishment projects. Increasing diversity, however, usually means increasing project costs, costs which may already be prohibitively high. This issue must be resolved. These wetlands need to function as wildlife habitats long after we are legally responsible for them. A

challenge for us is to continue developing low cost sources of diverse plant material and to design and implement wetland restoration and establishment projects with diversity in mind.

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Bottomland Forest Reestablishment Efforts of the U.S. Fish and Wildlife Service: Southeast Region, Ronnie J. Haynes,[1] Robert J. Bridges,[2] Stephen W. Gard,[3] Timothy M. Wilkins,[4] Harry R. Cook, Jr.,[5] (All authors are employees of U.S. Fish and Wildlife Service)

Abstract

Beginning in late 1987, the U.S. Fish and Wildlife Service (Service) began an aggressive effort to reestablish bottomland tree species, primarily within the Lower Mississippi River Alluvial Valley (LMRAV). Prior to 1987, the Service had planted several thousand acres on national wildlife refuge lands in the Southeast Region. The oldest planting is now about 24 years old. Since 1987, the Service has planted about 27,000 acres on lands transferred to the Service from the Farmers Home Administration and on private lands. The Service has used both the planting of acorns (primarily heavy-seeded oaks) and seedlings of selected species under a variety of conditions with variable degrees of success. In most cases, failures have been attributed to uncontrollable natural fluctuations in weather events (e.g., drought, flooding). However, other specific factors that possibly could have been controlled were noted (e.g., poor seed source, improper handling of seedlings/acorns, failure to properly match species with site conditions, etc.). A variety of cultural treatments and modified equipment has been used in these reestablishment efforts, including an experimental use of a small airplane to disperse acorns over the planting site. Monitoring approaches, data collected, issues needing additional attention and recommendations based on input from the Service's operational field staff are discussed.

Introduction

Extensive clearing and draining of bottomland forest ecosystems has occurred since the 1700's. For example, in the LMRAV, approximately 5.9 million acres (circa 1980's) of the original 24 million acres (circa 1780's) remain (Hefner and Dahl 1993).

Beginning in late 1987, the Service, Southeast Region, began an aggressive effort to reestablish bottomland forest ecosystems, with emphasis focused on restorable sites within the LMRAV. Efforts have been directed primarily to the planting of selected tree species [e.g., heavy-seeded oaks (*Quercus spp.*),

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cypress (*Taxodium distichum*)] on abandoned and/or marginal croplands, and the removing or modification of on-site drainage systems to restore or partially restore hydrologic functions. Efforts have been facilitated through our private lands initiative (Partners for Wildlife Program and implementation of the North American Waterfowl Management Plan), as well as through numerous opportunities available as a result of the 1985 and 1990 Farm Acts (e.g., Farmers Home Administration inventory lands, Conservation Reserve Program, Wetland Reserve Program) (Haynes 1992; U.S. Congress 1990, 1987, 1985; U.S. Department of Agriculture 1993, 1991; U.S. Fish and Wildlife Service 1986). Since late 1987, the Service has planted or contracted the planting of bottomland tree species on over 30,000 acres of various land types within the Southeast Region (Table 1). An additional 20,000 acres are targeted for planting (mostly within the LMRAV) over the next 5 years.

Table 1
Bottomland Forest Tree Plantings Since 1987: U.S. Fish and Wildlife Service, Southeast Region

Type	Acres[1]
Private	13,957
FmHA Transfer Lands	13,160
Other Refuge Lands	3,000
TOTAL	30,117

[1] Includes acres scheduled for planting in Fiscal Year 1993.

The purpose of this paper is to provide a summary of applied, operational information about the Service's bottomland forest planting efforts over the past 6 years. Most of the information presented herein was provided by Service biologists based on their field observations. These observations have not been statistically analyzed; thus, definitive conclusions should not be made, except in those cases where existing scientific information is adequate to support such conclusions. Information is provided under the following categories: site preparation, species planted as related to hydrology and soil types, planting methods and equipment, sources of plant material, planting times, and monitoring and research needs.

No effort has been made in this paper to provide a comprehensive literature review on this subject. However, in recent years the Service has published an annotated bibliography of bottomland forest reestablishment on disturbed sites (Haynes, Allen, and Pendleton 1988), a layman's guide to bottomland reforestation in the Lower Mississippi Valley (Allen and Kennedy 1989), and several other informative papers (Allen 1990, Haynes and Moore 1987).

Results

Site preparation

Site preparation is carried out to establish suitable conditions for tree seed or seedlings; or, in some cases to improve site conditions for the use of planting equipment and monitoring.

In carrying out tree planting operations, Service personnel typically minimize site preparation in order to reduce costs. Since the Service's planting objective is to ensure a timely reestablishment of heavy-seeded species in the forest ecosystem, and not commercial timber production, some mortality and reduction in growth due to competition from unwanted vegetation are acceptable.

Most field personnel have noted that site preparation may not be necessary whenever seedlings or acorns are to be planted on sites that have recently been in an active farming operation. However, over several years idle land may become so densely vegetated (including unwanted woody plants) that planting the site either by hand or with mechanized equipment is difficult, and mortality of young trees may become a significant problem. This may be especially true for exceptionally heavy growth of Johnson grass and vines, which have been shown to reduce germination and survival of young trees on some sites. Also, dense vegetative growth on a site prior to tree planting is conducive to high rodent, rabbit, and deer populations, thereby causing additional problems. Rodents will dig up and eat acorns, while rabbits and deer may eat young seedlings. In general, the longer an area lies idle before planting trees the greater the possibility of these problems.

The Service has used various types of site preparation methods. These include disking, mowing, burning, bush hogging, scalping, or various combinations. Disking of a site is almost always done within several months of planting. Mowing is limited by the size of woody vegetation on the site and may also be the least effective method. This is because mowed vegetation responds with rapid regrowth, possibly resulting in even more competition with the planted trees than would have occurred if the site had not been mowed. Burning is sometimes used when grasses and herbaceous plants occur on the site, but considerable planning and safety precautions are necessary when using this method. Probably the most widely used methods on sites that have been idle for several years is to bush hog or scalp (e.g., lower fire plow just enough to strip off vegetation) the area; then, disk one or two times just prior to planting the trees to remove any new vegetative growth and to loosen the soil.

Whenever acorns are direct seeded into heavy-clay soil types, double disking (two passes with the disk plow or harrow at a depth of at least 6 inches and preferably 8 to 15 inches) is recommended. Field observations have revealed that when acorns are planted in heavy-clay soil without disking, the soil often cracks at the seed furrow because of the use of the mechanized disk opener and packing wheels. Extreme temperature changes causes shrinking

and swelling of the clay soil, resulting in cracking of the soil and exposure of the acorn (often to extreme heat and drying), thereby causing mortality. Since disking can also create a harsh environment because the newly exposed seed-bed dries quickly, it is important that planted areas receive rainfall soon after planting. Whenever possible, Service personnel plan their planting to occur just prior to the passing of a weather system expected to produce rainfall.

The Service does not typically use fertilizers or herbicides in its tree planting operations. Although these amendments may be appropriate for commercial operations, any benefits to seed germination, growth, and survival of trees would seldom justify the additional costs given the Service's planting objectives.

Species planted/hydrology and soils

It is critical that the species selected for planting are matched to the hydrologic and soil conditions that exist and are expected to exist on the site. The plant-species composition of bottomland forest ecosystems is complex and variable, with certain species situated along environmental gradients that are strongly influenced by the degree (e.g., extent and duration) of flooding or inundation during the growing season. Over 100 species of woody plants may occur in periodically flooded bottomland ecosystems. These species exhibit varying degrees of adaption for survival in poorly-drained and poorly-aerated soils (e.g., from the wettest and most poorly-drained to drier and less poorly-drained). Considerable information is available regarding the adaptions of various bottomland tree species to hydrologic, edaphic, and other site factors (e.g., Burns and Honkala 1990; Wharton, et al. 1982; Clark and Benfirado 1981). A general rule of planting is that on an environmental gradient from the wettest to the driest site conditions a species that is adapted to poorly-drained and poorly-aerated soil conditions [e.g., cypress and overcup oak (*Quercus lyrata*)] can be planted successfully on drier sites, but species not adapted to such wet-soil conditions cannot survive when planted on lower sites.

Any competent natural resource manager is aware of these species-site relationships. However, failure to follow these requirements in actual site-specific planting situations is one of the most common causes of planting failures. For example, those responsible for planting may not have accurate site information regarding hydrologic cycles and soil conditions; without proper supervision and a clear understanding of the planting scheme, contractors may plant species inappropriately; very atypical situations may be encountered at the scheduled planting time (e.g., extreme drought or flooding), and trees are prematurely planted rather than waiting until planting conditions are suitable; or, appropriate tree seed or seedlings may not be available when needed, and the site is planted with marginal species, realizing that there is a risk of failure.

The Service has emphasized the planting of those species that are generally believed to need assistance in their establishment (especially on large,

abandoned cropfields where the distance to the nearest seed source is more than several hundred feet), and those species that provide important benefits to wildlife. Selected species have been planted (tree seed or seedlings) according to their adaptation to saturated soil conditions and flooding. Most often these have included: (1) cypress seedlings in the most frequently inundated areas; (2) moderately tolerant species such as Nuttall oak (*Quercus nuttallii*), willow oak (*Quercus phellos*), overcup oak, pin oak (*Quercus palustris*), green ash (*Fraxinus pennsylvanica*), and water hickory (*Carya aquatica*) on sites that may be saturated or flooded for up to several months during the growing season; and, (3) weakly or less tolerant species such as Shumard oak (*Quercus shumardii*), swamp chestnut oak (*Quercus michauxii*), cherrybark oak (*Quercus falcata*), water oak (*Quercus nigra*) (also somewhat moderately tolerant), and pecan (*Carya illinoensis*) on sites expected to be saturated or flooded for a few days to a few weeks during the growing season.

The Service has assumed that diversity of tree species on the areas planted will be achieved given sufficient time as a result of the lighter-seeded species invading by natural means from adjacent seed sources (e.g., wind-blown seeds). Some field personnel have recommended planting of invader species whenever the seed source is greater than 1/8 mile (660 feet). Additional research information on this subject is needed.

Planting methods and equipment

A variety of planting methods and equipment has been used, ranging from hand planting of seeds and seedlings to the use of modified farm equipment, and even broadcast spreading of acorns using a small airplane. Space limitations do not allow for an in-depth discussion of planting methods and equipment used, but considerable information is available in the literature (e.g., Allen and Kennedy 1989; Haynes, Allen, and Pendleton 1988). Only a few related topics have been selected for discussion herein.

In recent years, the Service has used direct seeding of acorns (primarily red oak species) extensively whenever seeds were available. This choice was made primarily because of the lower cost of direct seeding (about half or a third as much as planting seedlings). Considerable discussion within the Service and with other agencies has occurred regarding the merits and effectiveness of direct seeding and planting seedlings. Both methods have their advantages and disadvantages as summarized in Table 2. Although planting seedlings may result in faster initial establishment and growth, direct seeding in the LMRAV is expected to meet the Service objective of establishing selected heavy-seeded species in the forest ecosystem to achieve biodiversity and wildlife value, with a minimum investment of time and money (Allen 1990).

The Service usually sets a survival goal of about 125 planted trees per acre within 5 years after planting. Various planting densities for direct seeding or seedlings can be achieved by using different sowing and spacing patterns (Table 3). When direct seeding is used, a reasonable estimate is that only one

Table 2
Some Pros and Cons of Direct Seeding and Planting Seedlings

Pros	Cons
Direct Seeding	
Typically about half to one-third as expensive as planting seedlings.	Proven reliable only for oaks and some other large seeded species.
Roots develop naturally without problems caused by disturbing roots and removing seedlings from nursery.	Slower initial establishment and development, although long-term growth and survival may not be significantly different from seedlings.
Acorns may remain in a dormant state for a period of time under adverse site conditions (drought or too wet), thereby increasing survival potential.	Local acorn supply for one or more species may be scarce or difficult to obtain from commercial sources.
Can plant twice as fast, normally using a two-row planter vs. one row with a seedling planter.	Rodents can sometimes be a problem by digging up and eating the acorns; however, planting in large open fields typically results in little damage.
Proven method of reforestation when site is properly prepared using viable seed that has been properly stored.	Cold storage of acorns is generally limited to red oaks and sweet pecan. White oaks do not store well for periods greater than 3 months.
Window for planting is longer than for seedlings (acorns can usually be planted successfully from October through April or May).	Acorn-adapted planters (i.e., J.D. Max-Emerge 7100, converted) have more working parts, thus more potential for breakdowns than seedling planters.
	More difficult to monitor success, since it takes several years for germinated seedlings to become large enough to find easily.
Planting Seedlings	
Planting tree seedlings is a reliable and well established method of reforestation.	About 2 or 3 times as expensive as direct seeding of acorns.
Usually a good selection of reliable commercial suppliers of seedlings; seedlings available for many species.	Seedlings subjected to adverse site conditions (drought or severe flooding) will perish quickly.
Initial seedling development is faster than for planting acorns, although long-term growth and survival may not be significantly different.	Seedlings must be planted during the dormant period (January through March) when many bottomland forest sites may be flooded. Planting in extreme wet conditions must be done by hand.
Taller seedlings may be able to survive flooding events during the growing season if water does not top the seedling for extended periods.	Seedlings that have been fertilized in the nursery are a preferred food for rodents and deer.
For monitoring compliance and determination of planting success, planted seedlings are easier to locate than newly germinated seedlings from acorns or other seed.	

Table 3
Approximate number of trees planted per acre at selected spacings[1]

Spacing (Ft) : Trees/Acre[1]
6 x 10 : 725
7 x 10 : 620
8 x 10 : 545
9 x 10 : 485
10 x 10 : 435
10 x 15 : 290
10 x 20 : 220
10 x 25 : 175
10 x 30 : 145
11 x 12 : 330
12 x 12 : 300
4 x 15 : 725
5 x 15 : 580
6 x 15 : 485
7 x 15 : 415
8 x 15 : 360
9 x 15 : 320
11 x 15 : 265
12 x 15 : 240
20 x 20 : 110
15 x 25 : 120
20 x 25 : 90

[1] Assuming a 25 percent survival rate for direct seeding of acorns, reduce tree/acre by 75 percent for estimate of number of direct-seeded trees per acre.

out of four acorns sown will produce a tree still surviving after 10 years (25 percent survival rate). Using this survival rate, planting acorns on a spacing of 9' x 10' would yield an estimated 121 trees per acre. With seedlings, higher survival rates are expected (Allen 1990); thus, planting on larger spacings (e.g., 12' x 12' or 12' x 15') is recommended (Table 3).

Recent field observations have suggested that greater overall tree species diversity may be achieved by using wider spacing than the Service has

typically used. For example, by increasing the spacing from 12' x 15' to 20' x 20', the number of planted seedlings per acre would be reduced from about 240 to 110 trees per acre, respectively. Many biologists believe that as few as 80 or 100 planted trees per acre would be sufficient for wildlife purposes, and to achieve a reasonable representation of heavy-seeded species in the forest ecosystem within a 50-year time period. Thus, greater spacing between planted trees might allow a better "window of opportunity" for invading tree species (shade intolerant) to become naturally established on the site. Additional research on the effects of various planting spacings and natural invasion of tree species is needed.

The Service has also recently experimented with direct seeding of acorns by broadcasting them from a small airplane. In general, the area to be planted is double disked or cultivated prior to broadcasting the acorns. Acorns are segregated according to their size and loaded into the hopper of a crop dusting type airplane. The openings on the hopper are typically set about 1/8 of an inch wider than the largest acorn. The pilot flies a test run with about 50 pounds of acorns in order to calibrate speed and distance between flight lines to obtain the coverage desired. With the airplane used by the Service in one test planting and flying at its slowest speed and altitude of about 90 feet, a strip 63 feet wide was covered with acorns on each pass. Acorns were then disked into the ground and a drum roller was used to compact the loose soil over the acorns and to help seal in soil moisture.

Following an aerial seeding of an abandoned crop field in April of 1992, the field was checked for germination in June. Some areas exhibited numerous young seedlings of both willow and Nuttall oak, whereas no germination was noted on other parts of the same field. Additional field testing of the aerial seeding method is ongoing. Presently, it is too early to make any definitive conclusions about the spotty initial germination, or whether or not the benefits of aerial seeding outweigh any disadvantages. Additional research information on this planting method is needed.

Sources of plant material

The Service recommends that tree seeds and tree seedlings be obtained from local vendors or sources within 75-100 miles north or south of the proposed planting site. This distance could be greater if the source is from about the same latitude. Seed or seedlings from local plants are presumed to be more genetically adapted to the full range of site conditions that may be encountered, thereby increasing the likelihood of long-term survival and reproduction of the planted trees.

In recent years, the number of local vendors and availability of bottomland tree seed and seedlings has increased, as greater emphasis has been directed to the planting of bottomland tree species through a variety of incentive programs (e.g., Conservation Reserve Program, Wetland Reserve Program, Forest Stewardship Program, Service tree planting initiatives, etc.). Other potential sources

of assistance include State Forestry Commissions and private timber companies.

Over the past few years, Service employees and local volunteers have collected numerous acorns (mostly red oak species) for cold storage. On a good day, one person can collect as much as 50 pounds of Nuttall oak acorns. Acorns are usually tested for viability by use of the "float test." For this procedure, acorns are placed in a large container of water; those acorns that float are skimmed off and discarded. Those that sink are presumed to be good, are placed in plastic bags (4 mil), and then into burlap sacks. The burlap sacks are then stored in a cooler at about 35-40 degrees Fahrenheit. Many red oak species (i.e., larger acorns) can be stored successfully for up to three years, whereas white oak species (e.g., overcup and swamp chestnut) can be stored for only a few months at best.

Planting times

In the LMRAV, acorns exhibit best germination and survival when planted from late fall (e.g., November 1) through the end of May. Seedlings are best planted during the winter dormant season (e.g., beginning about January 1) through mid-March. The Service has obtained varying degrees of planting success and failure throughout all months of the year; however, the lowest survival rates have occurred during the months of June, July, and August. Typically, the Service no longer plants during these months.

Monitoring

Because of limited funding and personnel, the Service has not often been able to conduct extensive scientific monitoring of its tree planting efforts to the extent desired or needed to obtain optimum information. In many cases, only visual spot checks (one or several times a year) to assess germination and survival have been possible; however, more intensive monitoring efforts have been carried out on some sites.

Field personnel recognize the importance of monitoring reforestation efforts in order to evaluate the success or failure of various planting methods under different environmental conditions, and to obtain information that may prove helpful in future planting efforts. In this regard, a summary of some recommendations from field personnel, based on their applied experiences, is provided below.

a. Establish a goal and measurable criteria for determining success or failure of the planting effort. For example, from the Service perspective a planted site may be considered successful if the average stem count of planted species is at least 125 stems/acre after several growing seasons. However, from a commercial timber harvest perspective, 125 stems/acre would probably be considered a failure. Another

criteria could be that if the planted species and natural invaders of the same species are less than one-third of the total species onsite, a supplemental planting should be considered.

b. Seedlings should be sampled by flagging each individual seedling along each row for a given distance (e.g., 50 feet) to achieve the desired sample size. For both seedlings and acorns planted in rows, use a 1-foot sampling zone on either side of the row for the specific sampling distance (e.g., 50 feet). A 2-percent sample of the total area planted is recommended.

c. Mark planting rows with clearly visible engineering flags placed about every 10 feet. Flags colored other than red or orange are recommended, since rodents and other wildlife (e.g., nutria and beaver) seem to be attracted by red and orange colors. It is especially important to mark rows when acorns are direct seeded, because newly germinated seedlings are extremely difficult to find in dense cover for the first 3 or 4 years after germination. There have been several cases where areas planted with acorns were initially thought to be failures following sampling after the first growing season. However, subsequent sampling, after several years when the young seedlings had grown to sufficient size to be more easily seen, revealed that the plantings were actually a success.

d. When fields are not planted in rows (e.g., aerial seeding of acorns, broadcast spreading, natural invasion), circular or rectangular plots can be used to obtain a 2 percent sample. For example, if the planted area is 100 acres and a rectangular plot size of 100' X 15' is used, then 59 sample plots of this size are needed to achieve a 2 percent sample. For long-term scientific purposes, mark plots permanently (e.g., magnetic markers buried underground).

e. When plots are used, randomly locate sample plots according to existing terrain. For example, if the terrain and environmental conditions (e.g., hydrology, soil types) of the area to be planted are mostly homogeneous, plots can be located randomly along the planting rows. If the terrain and environmental conditions vary in a recognized manner over the area, the different zones should be delineated, and a sampling scheme that includes representative samples across all identified zones should be implemented. Data should be evaluated separately according to the various zones identified.

f. Sampling for germination and survival is best done during the fall and early winter, when the leaves have changed color and other vegetation is dying.

g. Count all tree species encountered within a sample plot. Both the species planted and the natural invaders will comprise the future forest ecosystem. The species information to be obtained about natural

regeneration is critical to understanding succession and species-site relationships.

h. All bottomland reestablishment projects should have a required follow-up monitoring plan included as an integral part of the total project cost.

Research needs

There are numerous interacting environmental factors that may affect the germination, growth, and survival of both planted and naturally invading species. Accordingly, there has been considerable research conducted relative to the reestablishment of bottomland forest species as influenced by many different environmental conditions (e.g., Haynes, Allen, and Pendleton 1988). However, there is a continuing need for additional repetitive studies to help validate the results and conclusions derived from previous studies. Furthermore, there is a great need for more research on natural succession and species diversity on both planted and unplanted areas. These studies should span a longer period of time than the 3- to 5-year follow-up monitoring studies often associated with projects and then forgotten over time. Most researchers recognize these long-term study needs, but find it difficult, if not impossible, to obtain a project funding commitment past 3 to 5 years.

The Service has recently increased its efforts to obtain scientific information about the restoration of bottomland forest ecosystems. For example, field project leaders have been encouraged to conduct follow-up monitoring of their planting operations and to maintain marked plots for future studies. One cooperative study involving the Service, Soil Conservation Service, Environmental Protection Agency, and the Louisiana Forestry Commission began in 1992 and will continue at least through 1995. This study is being carried out by the Louisiana State University Cooperative Fish and Wildlife Research Unit, and will evaluate various reforestation methods used under a number of site conditions and treatments. A similar study on a large tract (about 2,600 acres) of abandoned agriculture land (i.e., prior-converted cropland and farmed wetland) in Mississippi, involving the Service and other Federal and State agencies and the forest industry, is currently being planned for implementation during 1994. Also, the Service's National Wetlands Research center in Lafayette, Louisiana, began a research initiative that focuses on the reestablishment and biodiversity of bottomland forest ecosystems. Other Federal agencies such as the Corps of Engineers (e.g., Waterway Experiment Station, Vicksburg, Mississippi), Environmental Protection Agency, Soil Conservation Service, and U.S. Forest Service (e.g., Southern Forest Experiment Station, Stoneville, Mississippi) are also continuing or increasing their research efforts on bottomland forest ecosystems.

Conclusion Statement

Since 1988, the Service has planted over 30,000 acres of bottomland tree species on previously cleared lands within the LMRAV. The Service also plans to plant an additional 20,000 acres over the next 5 years. Although much information has been obtained, there is still much more to be learned. Many of the Service's plantings have been judged to be a success; others have failed for many different reasons. These failed attempts have been or will be replanted. Much of the information gained has been through trial and error methods; thus, we continue to learn from our mistakes, as well as from the work carried out by others.

We believe that a significant philosophical bridge has been crossed over the past 8 to 10 years. That is, we have moved ahead from the period of documenting the significant losses of bottomland forest ecosystems, and the Federal subsidizing of the drainage and clearing of these ecosystems, to an era where many influential parties (government, nongovernment environmental groups, private citizens, industry, and others) now clearly recognize the wide-ranging significance and economic importance of our bottomland forests. Many of these parties are now dedicated to restoring bottomland forest ecosystems whenever and wherever opportunities are found. Many new and innovative ideas are being generated to encourage landowners to protect and conserve these forest systems.

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Bottomland Hardwood Mitigation for Reservoir Construction - Status and Influence of Exotics in Topsoil, D. S. McGrain, D. J. Frederick and E. C. Franklin, Graduate Research Assistant and Professors respectively, College of Forest Resources, North Carolina State University, Raleigh, NC

Introduction

Early in 1992, Cabarrus County, North Carolina contracted with North Carolina State University to implement the mitigation plan associated with a 445-hectare drinking water reservoir on Coddle Creek. Coddle creek is in central North Carolina on the upper Piedmont. The plan includes approximately 78 hectares of forested wetlands and 80 hectares of forested uplands. Over 300,000 seedlings, representing 20 tree and shrub species, will be planted on these sites adjacent to the reservoir. An additional 12-hectare forested wetland creation site comprised of cut and fill material capped with topsoil will be constructed in 1993-94. Old-field upland soil and donor topsoil from an adjacent bottom land hardwood forest will be used on the creation site. Several bottom land hardwood species will be planted on the contrasting topsoil.

A critical research gap identified by Clewell and Lea (1990) pertained to developing techniques for wetland forest undergrowth establishment, potentially 90% of total forest species composition. One of the most effective ways to establish native undergrowth vegetation is to use donor topsoil from a nearby site with appropriate vegetation (Leck, 1989). The size and composition of a seed bank is the result of past and present plant communities in terms of ecological and genetic diversity (Harper, 1977; Baskin and Baskin, 1978). Although seed banks show an exponential decline with depth, variation occurs within and among wetlands (Leck, 1989). Terrestrial soils can show a sharp decline over a few centimeters of depth (Kellman, 1970; Moore and Wein, 1977). Objectives of the **Seed Bank Depth Germination Study** were: 1) determine the number of germinants per sowing area at three depths for the old-field and bottom land hardwood forest topsoil and 2) determine which topsoil contains native species desirable for revegetation.

North Carolina requires cover crops be used to comply with erosion and sedimentation control regulations on reservoir boundaries. Introduction of exotic cover crop vegetation can reduce establishment of native vegetation and adversely affect planted trees (Vogel, 1980; Brenner et al., 1984). Seeds and propagules contained in a seed bank can provide native vegetative cover and assist in stabilizing topsoil (Farmer et al., 1982; Erwin and Best, 1985) Objectives of the **Seed Bank Exotic Species Treatment Study** were: 1) determine the competitive impact of an exotic cover crop **German millet**, Setaria italica L., on a bottom land hardwood forest seed bank diversity and 2) determine the

potential for the native seed bank to provide adequate vegetation without the addition of an exotic cover crop.

Materials and Methods

Study sites

Study sites were located southeast of Bradford Road (NC 1604) near Concord, North Carolina. Climate was temperate with an annual mean maximum temperature of 22 °C and minimum of 8 °C. Monthly rainfall averaged 9.27 cm. Appling and Enon sandy loam soils dominated the upland old field site. Chewacla, a somewhat poorly drained alluvial soil, underlain the adjacent bottom land hardwood forest. Aster pilosus Willd., Erigeron strigosus Muhl., Lespedeza bicolor Turcz., Festuca spp. L., and Andropogon virginicus L. were numerous in the 2-3 year upland old field. Abundant woody species in the bottom land hardwood forest include *Liquidambar styraciflua* L., *Juniperus virginiana* L., *Ulmus alata* Michaux, *Ulmus americana* L., *Platanus occidentalis* L. and *Carpinus caroliniana* Walter. *Microstegium vimineum* A. Camus., an exotic, Asian, annual grass dominated the forest undergrowth. The first U.S. herbarium specimen of *M. vimineum* was collected in 1919 by G.G. Ainslee along a creek bank in Knoxville, Tennessee. In the last seventy years the geographical range and types of habitats occupied by the species have continued to increase (Fairbrothers and Gray, 1972).

Soil collection

Seed Bank Depth Germination Study. In November 1993, PVC pipe, 10 cm X 30 cm, was used to collect 30 soil samples in the upland old field and bottom land hardwood forest. Pipes were driven into the soil with rubber mallets. Cores were removed with shovels and placed in refrigerators at 0-5 °c until January 10, 1993 when each core was removed and vertically divided in half. Half was discarded and the remaining half was divided into three segments, each 10 cm in length. Each soil segment was separately spread onto the same 45 cm X 25 cm plastic tray. Overhead lighting increased the photo period to sixteen hours and the greenhouse temperature averaged 24 °C. Trays were periodically watered with 8-12 ounces of 10-10-10 fertilizer. Seedlings were removed from the trays once identified and counted. Taxonomy followed Radford, Ahles and Bell (1968). On June 15, 1993, the study was terminated. PC-ORD cluster analysis was performed on the seedling emergence data using Ward's method and euclidean distance (McCune, 1991).

Seed Bank Exotic Species Treatment Study. In the companion greenhouse study bottom land hardwood forest topsoil was collected to a depth of 30 cm from four randomly selected areas in January, 1993. Soil from each area (block) was thoroughly mixed and spread 10 cm deep onto six plastic trays, 54 cm X 60 cm. Each tray was randomly assigned one of six treatments (Table 1). When appropriate, German millet seed was incorporated into the

top 1/2 cm and 10-10-10 fertilizer into the top 5 cm of soil. Spring growing conditions were simulated in the greenhouse, as described in the previous section. In April 1993 the study was terminated as vegetation densely covered each treatment tray. Abundant species were separated and counted and remaining seedlings were treated as a single group. Taxonomy followed Radford, Ahles, and Bell (1968). Biomass was measured by the harvest method (Conner and Day, 1976).

Table 1
Description of Exotic Species (Cover Crop) and Fertilizer Treatments Used on a Disturbed Bottom Land Hardwood Seed Bank

Treatment #	Description
1	1 g of German millet seed (approx. 360 seeds)[1]; 10 g of fertilizer[2]
2	1/2 g of German millet seed (approx. 180 seeds); 10 g of fertilizer
3	1 g of German millet seed
4	1/2 g of German millet seed
5	10 g of fertilizer
6	Control

[1] ~ to 20.24 lbs/ha.
[2] ~ to 202.4 lbs/ha of 10-10-10 fertilizer - recommended rate (NC ESCM).

Results

Seed bank depth germination study

Bottom land hardwood forest topsoil yielded more seedlings at all depths and a greater percentage of seedlings at deeper depths compared to upland topsoil (Table 2). *M. vimineum* comprised over 50% of the total number of seedlings in the bottom land hardwood seed bank. It was most abundant in the shallower depth, representing 58% of all seedlings. In depths 2 and 3 it represented 34% and 19% of all seedlings, respectively. *M. vimineum* seedlings germinated early, in the first few months. Once removed, native plants including several species of *Juncus*, *Cyperus* and *Ludwigia* as well as *Mimulus ringens* L., *Hypericum mutilum* L., *Eleocharis obtusa* Willd. and *Samulus parviflorus* Raf. germinated. The upland seed bank was dominated by *Gnaphalium purpureum* L., *Veronica arvensis* L., *Sagina decumbens* Ell., *Oxalis spp.* L., *Specularia biflora* R. & P. and *Cerastium glomeratum* Thuillier. Cluster analysis revealed each topsoil had a distinct plant community and a distinct cluster at the shallowest depth.

Table 2
Means and Ranges of Seedling Germination Totals From Three Soil Depths for an Upland and Bottom Land Hardwood Seed Bank

Soil Depth	Totals	Mean (germ./m^{-2})	Range (germ./m^{-2})	Totals	Mean (germ./m^{-2})	Range (germ./m^{-2})
	Bottom land'			Upland		
1 (0-10 cm)	2,477	653	1,447-245	1,937	511	1,194-103
2 (10-20 cm)	819	216	482-79	483	127	672-16
3 (20-30 cm)	428	113	253-40	146	39	150-0

germ. = germinants

Seed bank exotic species treatment study

Total stem numbers did not vary significantly among treatments. Biomass was greatest in treatment 5 where millet seed was not added but fertilizer was incorporated into the soil. *M. vimineum* readily germinated from the disturbed seed bank and dominated each tray, among all blocks. It comprised greater than 73% of all stems and total biomass in each tray and increased to over 90% of both measures in treatments 5 and 6. A few species, primarily *Stellaria media* L., *Oxalis dillenii* Jacquin., *Caradmine hirsuta* L. and *Rumex acetosella* L. also germinated from the seed bank representing less than 10% of total stems and biomass (Table 3).

Table 3
Means and ranges of biomass and density for total species and species groupings in a bottom land hardwood forest seed bank exotic species treatment study

Trt #	Mean (g/m^{-2})	Range (g/m^{-2}) (%)	M.V. (%)	G.M. (%)	OT. (st./m^{-2})	Mean (st./m^{-2})	Range	M.V. (%)	G.M. (%)	OT. (%)
	Biomass					Density				
1	71	99-40	73	21	6	1563	1,796-1,391	73	21	6
2	66	95-48	74	20	6	1260	1,800-988	74	17	9
3	34	42-24	74	19	7	1582	2,063-1,188	76	18	6
4	52	97-24	83	12	5	1539	2,074-924	86	7	7
5	72	118-36	94	0	6	1465	2,049-910	91	0	9
6	36	55-19	94	0	7	1155	1,525-766	92	0	8

M.V. = M. vimineum; G.M. = German millet; OT. = All remaining seed bank seedlings
st. = stems.

Discussion

M. vimineum has invaded floodplains, streambanks, and adjacent mesic slopes in the North Carolina, Piedmont during the last 30 years and is particularly invasive in disturbed areas. Its seeds are known to remain viable in the soil for at least three years and moisture status rather than soil fertility appears to limit its growth and development (Barden 1987). The abundance of this exotic grass in the vegetation and the disturbed seed bank of the bottom land hardwood forest indicates intense seed production and high viability. Only twelve taxa germinated from the bottom land hardwood forest topsoil along with *M. vimineum* and German millet.

Although *M. vimineum* was the dominant species in the forest seed bank, native species desirable for forested wetland restoration and creation efforts were also present. Under field conditions, respread topsoil may yield dry soil conditions unfavorable to *M. vimineum.* Canopy closure usually results in the suppression of noxious weed species and favors desirable forest undergrowth plants (Clewell and Lea, 1990). However, *M. vimineum* is capable of substantial growth even at 5% full sunlight (Winter *et al.*, 1982) and thrives in the cooler, moister conditions available under a forest canopy. Historically it has invaded mesic shaded areas where floods scour existing vegetation, but is also capable of migrating slowly into areas with established undergrowth vegetation (Barden, 1987). Under greenhouse conditions, *M. vimineum* out competed an introduced exotic species and native seed bank vegetation resulting in decreased native species diversity. Field trials are needed to determine its role and impact on native topsoil vegetation in wetland restoration and creation projects.

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Specifications in Wetland Mitigation, Ken Dunne, Lewis Morgan and Mahendra Rodrigo, Louis Berger and Associates, Inc., East Orange, New Jersey

Introduction

A typical engineering bid package consists of construction plans and construction specifications. Construction plans include site plans showing existing and proposed features, construction details, project notes specific to the particular project and quantities of pay items. Construction specifications provide a clear description of the work performed under a particular pay item including material and equipment to be used, method of construction, method of measurement and payment. In general, construction plans represent "What to Do" while specifications represent "How to Do" a particular task. Although a sound design is required for the development of a constructed wetland, the quality and completeness of the specifications plays a major role in the determining the success of the mitigation with the specification representing safeguards against poor construction practices and utilization of material with inferior quality. Mitigation designs are likely to fail as much from poor specifications, as from poor designs.

A specification can either be a construction specification or a material specification. Material specifications provide the properties and the standards of construction materials. Construction specifications describe the entire construction process of a particular task or describe the required properties and the standards to be met by the final product. Construction specifications frequently refer to material specifications, unless a complete description of the materials to be used is provided within the text of the construction specifications.

Many engineering organizations, such as the U.S. Army Corps of Engineers, all highway departments, and utilities possess their own "Standard Specifications" and "Standard Details," mainly due to the repetitive nature of the work. This practice greatly reduces the specifications writing effort and, in the many bid packages, the specifications are referenced by the code number and title only. However, supplemental specifications may be developed and/or standard specifications may be amended for a particular contract requiring the inclusion of "unconventional" items that are not covered by standard specifications. In addition, many engineering specifications reference standards published by organizations such as the Corps of Engineers, AASHTO (American Association of State Highway and Transportation Officials) or the ASCE (American Society of Civil Engineers). As much of the landscape work associated with wetland mitigation represents relatively new construction practices, there is no standard specifications source to reference. In many engineering organizations, these supplemental specifications are then added to the "organizational memory" for use in future projects.

Uniqueness is one of the major considerations in developing specifications. In other words, overlapping of work tasks in two specifications items or not properly accounting for a particular task in a construction specification could result in an increase in the cost of construction and/ or an inferior product.

Plans, details and specifications are all an integral parts of the bid package representing distinctive aspects. Plans are engineering drawings. Details are line drawings representing a desired action, item or construction practice. Specifications are written guidelines associated with each and every pay item or action included in the contract. Specifications are not associated with species selection (except in seeding mixtures), quantities, species placement, water depths or grading plans. These latter items are all associated with plans. If desired, specifications can reference details, but details are not specifications. The drafting of specifications is a technical effort that must include certain elements -- DESCRIPTION, MATERIALS, CONSTRUCTION METHODS, METHODS OF MEASUREMENT, AND BASIS OF PAYMENT. The headings and format for representing these elements may vary somewhat between various agencies, but the basic elements are represented. The most common deviation from this format occurs when the material specifications are separated from the construction specifications, but when taken together all the basic elements are represented. For landscape items, additional headings that are common include (1) PLANT ACCEPTANCE and (2) PLANT ESTABLISHMENT PERIOD.

Development of Specifications

Specifications are written guidelines for performing a specific task at a minimum standard of performance and the payment for that work. Specifications are written in an "engineering legalese" and should be viewed as being part of a legal document. As legal documents, the Contractor's sole responsibility is to perform the work as described in the plans, specifications and details. As long as the Contractor follows those guidelines, the Contractor will be paid, even if the work is a clear and immediate failure.

When developing wetland planting specifications and details, one **must** assume that the Contractor performing the work knows nothing about wetland mitigation, cares nothing about wetland mitigation, and is bidding on the job simply for the monetary award. In addition, one should not assume that the Contractor is overly intelligent. Nor can one assume that when the project is being constructed and the planting installed that anyone familiar with the drafting of the specifications or plans will be present. Therefore, the specifications must include not only detailed provisions for directing how the work should be performed, but should include detailed provisions indicating what actions are prohibited.

Within specifications, the term *Engineer* is a reference not to the Contractor or the design engineer, but to the individual(s) whose responsibility is focused on insuring that the work is installed in full accordance with the plans and

specifications. The *Engineer* is either an employee of the parent organization authorizing the work or a consultant to the parent organization. The *Engineer* is not employed by the Contractor. For the remainder of this paper, the word *Engineer* will be restricted to this usage.

Quality control is the ultimate responsibility of the *Engineer*. However, the *Engineer's* ability to insure quality control is limited to that contained within the specifications, a legal contract document for work to be performed. The *Engineer* can authorize deviations from the specifications, but if major revisions are necessary the process is awkward and can result in a laborious paper trail of "Change Orders" or "Modifications." *Engineers* should not be handicapped by poorly written specifications.

Ideally, one would like to utilize professionals that are experienced in the field of wetland mitigation. However, experienced wetland mitigation construction contractors are relatively few, and if the pre-qualifications are too narrow or restrictive, the advertisement of such a specification may result in various legal problems and challenges. In addition, the parent organization which reviews the contract documents is likely to strip such pre-qualifications from the final bid documents for legal or policy reasons. For most publicly bid wetland mitigation contracts, especially those associated with flood control work or highway construction, the mitigation plans are bid as a single contract and not a series of subcontracts. As such, it is likely that the driving force on the bid award will not be the planting or landscaping costs but engineering costs, especially earthmoving. The engineering costs can easily exceeded 90 or 95 percent of the total contract award.

Specification Elements for Wetland Landscaping

As there is no standard reference for wetland landscaping specifications, the remainder of this paper will focus on landscape elements. However, Garbisch (1989) does provide many valuable insights into the development of successful design packages. Landscaping Specifications for wetland mitigations are not confined to simply providing planting lists and methods for installing or seeding plants, but must encompass all aspects of the planting. When writing specifications, one must realize that most construction contracts are between the parent organization, as administered by the *Engineer*, and the Contractor. For most contracts, neither the Contractor nor the *Engineer* is under any obligation whatsoever to communicate with the design team. Therefore, the specifications must be of sufficient detail and quality to insure that items being requested can be properly installed, as per the bid package.

Within planting specifications, there are references to many non-plant items, such as fertilizer, stakes and cords. These items are not Pay Items, but are considered incidental to the item under consideration. Although incidental, these items must still have an accompanying material specification. Among the elements that may be included in wetland landscape specifications are the following (not presented in engineering legalese):

Description: Short concise task description.

Materials: Detailed description of all materials including plants, seeds, fertilizer, stakes, cords and incidental items. Depending on contracting rules, the description of the materials may include brand-names, but one may have to utilize generic material descriptions. Quality control through material testing may be appropriate for some items. Sometimes it is desirable to identify the **genetic** origin of the plant material by geographical region. A taxonomic reference for species selection should also be given. If wet-grown woody plants, salt marsh plantings or other specialized materials are required, the material specification must include detailed requirements for the growing conditions under which the materials are propagated. If large quantities of landscape materials are required, separate growing contracts can be bid. If materials are of poor quality and are outside the specification guidelines, the *Engineer* may elect to reject any material without compensation to the Contractor.

Construction methods

a. A requirement that the Contractor must submit vendor purchase orders for all plant materials within a certain period of time subsequent to the award of the Contract.

b. If the Contractor indicates that some planting items are not available, the Contractor must provide a brief written explanation of the purchasing problem and a list of vendors contacted. The *Engineer* will likely then contact the design team to discuss the purchasing problem. The design team will then verify the problem or provide a list of appropriate vendors.

c. No substitutions should be allowed unless authorized by the Parent Organization. This may force the *Engineer* to contact the design team for technical input.

d. If any substitutions have been authorized, the Contractor must submit reproducible drawings showing the approved changes at the same scale as the bid landscape sheets, two months prior to the plantings. A paper trail outlining the generation of all the approved changes must be included in this submittal by the Contractor. This will allow the *Engineer* and the design team to review the planting plan prior to the actual planting.

e. If the landscape design is intricate, the layout should be staked according to a set numbering pattern as shown on the plans. This will greatly aid in any subsequent inspection or monitoring of the planting.

f. Identify the appropriate planting season(s) by calendar date. If high energy system or a long fetch is anticipated and the planting is for an

aquatic site, a fall planting should only occur at the direction of the *Engineer*.

g. Plant storage and handling guidelines should be presented. During storage, transit and installation, plant materials should be kept covered, cool, moist and kept from freezing.

h. The specifications should contain a material description for all planting media, including marsh soils. For some plantings, specifications can be limited to the pH range and soil texture requirements, such as limiting the maximum clay content.

i. Given the opportunity, most wetland plant material will **FLOAT**. Therefore, the specification for setting plants must be very clear as to proper installation procedures. Identifying the type of machinery or tools is not necessary, however, plant handling, planting depths and subsequent soil compaction need to be addressed. If installed properly, weighting of marsh plants is not required.

j. For many plantings, any fertilizer that needs to be placed should be placed at the bottom of the planting hole and no fertilizer should be placed in the water column. The appropriate fertilizing formula or rate can change with the planting season. **WARNING:** Most native grass seed mixtures are warm season grasses. These warm season grasses have a totally different biology than the common cool season "lawn mixes." A cool season fertilizing program with a warm season grass mixture is likely to "destroy" the warm season stand.

k. Include a requirement for As-Built Plans at a designated scale.

l. With non-tidal marsh mitigations, a Pay Item for the flooding of the marsh should be included to prevent desiccation of the newly installed plants. Payment is restricted to the volume of water actually pumped and not obtained via weir adjustments.

m. Planting under flooded conditions is much more difficult than non-flooded conditions. For non-tidal marsh mitigations, one should include a Pay Item for the dewatering prior to the actual planting. Payment is restricted to the volume of water pumped and not removed by draining via weir adjustments.

n. The acceptance of most plant materials for wetland mitigation should be based on **the quality of the materials and the quality of the installation**. Therefore, the authors favor limiting the acceptance period to about a month or even less, following the planting and/or the setting of the hydrology. However, plants found that are not properly installed, found floating, or found in the water column will not be accepted.

o. The authors do not recommend the adoption of a plant establishment period. For wetland plantings, this condition may not be enforceable and will substantially increase the unit bid price for those items.

p. If waterfowl herbivory is a concern, a specification for waterfowl fencing as an IF-AND-WHERE-DIRECTED ITEM may be appropriate (Garbisch, 1986). A better choice may be brush fences that can be used to cordon-off planting areas. Such fences are used in Germany, but the authors know of no installations in the United States.

Method of Measurement. Indicates the unit of measure for payment. This can be almost any unit of measure including per plant, square foot or lump sum.

Basis of Payment. Indicates what pay items are included under the specification. It also includes lists of actions, use of equipment and tools, and required materials that are incidental to the pay items.

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Wetlands Bioengineering for Erosion Control on Reservoirs, Burl D. Ragland, Civil Engineer, P.E., Tulsa District, Corps of Engineers, Hollis H. Allen, Ecologist, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, John H. Brigham, Project Supervisor, Tulsa District, Corps of Engineers, Michel D. Dunford, Project Ranger, Tulsa District, Corps of Engineers

Background

Erosion control on many reservoirs is a significant problem. The cost of slowing down the erosion process is consuming valuable resources and is not always producing the desired results. Therefore, the need exists to produce cost-effective methods of controlling erosion on reservoirs that will benefit both man and the environment. This need and the willingness of the U.S. Army Waterways Experiment Station (WES) and the Tulsa District (TD) Corps of Engineers to support an erosion control testing program, enabled the design and construction of two special test sites on Lake Eufaula, Oklahoma. Details of planning, implementation, and preliminary results of these bioengineering test sites are provided in this paper.

Planning

Lake Eufaula, Oklahoma, has been experiencing severe erosion problems for several years. The negative impacts of erosion continue to be exacerbated by the land acquisition policy in effect when the reservoir was constructed. A minimum amount of real estate was purchased under that policy. Thus, shoreline erosion is quickly progressing beyond the Government property line onto private property. The Corps has purchased several lakeside homes that were endangered by shoreline erosion. Beginning in the mid-1980's, the TD began to study and construct erosion protection projects using traditional methods such as riprapped revetments. Shortly after this initiative, a survey of the entire shoreline was made and about 22 miles of it was determined to need erosion protection. During this evaluation process, it became apparent that more economical and environmental pleasing erosion control measures are necessary.

Test sections using both stone protection and bio-engineering methods were developed after the survey. The survey and preliminary tests resulted in a report. Recommendations in the report suggested that a combination of plants and stone protection be used to correct the problem. More specifically, it suggested using solely stone protection in certain places, solely vegetation in others, and a combination yet in other places, depending on the causes, magnitude, and potential consequences of erosion. Since the report, the TD has

tested several erosion control techniques and most of these have been successful, but costly. Additional testing using bioengineering methods was made possible by a partnership arrangement between the TD and the WES where research monies were used for two demonstration test sites.

The specific test sites were selected in April 1992 and are located near a real estate development named AH-DU-PAH. The demonstration sites were about 100 feet in total length. The end sections were 45 percent to shoreline and extended about 30 feet into the lake. The center sections were about 40 feet long. The sites are characterized by a sandy beach area with about 20- to 30-foot bluffs behind each. The average fetch, the distance across water to produce a wave, is 3 to 5 miles and the site is often subjected to heavy wave action because of the fetch and periodic storms that produce substantial winds both from the northwest in the spring and summer and the southeast in the winter. This situation offers a challenging scenario for the test sites and bioengineering methods used at each.

The general concept used at both test sites was the combination of a breakwater to break the erosive action of waves and wetland vegetation to further dampen waves, trap sediment, and hold soil particles together. The vegetation would continue to spread and heal the cutbank behind it. This concept was predicated on a similar concept successfully used in Germany and described by WES (1992). The two sites differed primarily in the types of breakwaters used: the easternmost site employed a branchwater breakwater made from dead branches bundled and stacked as described by WES, 1992; the westernmost site employed stacked rolls of coconut fiber encased in a coconut rope mesh. Additionally, a 1-foot high gabion was used in front of the coconut fiber roll breakwater because of the perceived heavy wave action. Along the flanks of each breakwater, 1-ft-deep by 3-ft-wide gabions were run up onto the beach to prevent the sites from receiving wave-scour at the sides.

A configuration of three rolls was used for the coconut fiber breakwater. The rolls were stacked in a pyramid fashion: two on the bottom and one on the top. As an extra precaution to prevent scour from occurring underneath the rolls, coconut fiber mats were used under the rolls.

Coconut fiber mats were used landward of each breakwater and were sprigged (use of rooted plant stems) with wetland plants early in the spring of 1992 at a nursery located at the Lake Eufaula Project Office. The mats were later moved to each site in October, 1993 with plants growing all over and throughout them. Under normal circumstances, it is preferred that this be done in the early spring to take advantage of a longer growing season, but this was not possible due to constraints of initiating a contract. Plants grown in the mats consisted of softstem bulrush (*Scirpus validus*), broadleaved cattail (*Typha latifolia*), and common reed (*Phragmites australis*).

The mats, with their coconut fiber content, resemble fibrous root systems. When they are sprigged with plant stems, they shortly become covered with plants in about 3 months, depending on the environment. These mats, in turn,

encourage rapid root establishment on the substrate over which they are placed. Such a mat/plant system possesses high tensile strengths, is durable, and acts like a filter to trap fine soil particles, but pass water. Ten 5- by 6-ft mats were placed in a staggered fashion to cover the 2,200 sq ft area behind the breakwater at each site. The concept is for the pre-grown plants to quickly stabilize the soil beneath the mats and spread throughout the site. To further encourage the rapid development of the wetland, other individual plants were interspersed among the mats. These consisted of the same plants sprigged in the mats. Landward and somewhat higher in elevation, sprigs of switchgrass (*Spartina pectinata* var. Kanlow) were planted on about 0.5-ft centers above the mats. Switchgrass is a prairie grass that can grow in periodically wet environments. All of the plants used are either native or have been naturalized in the area.

Construction

The test sites were constructed by the use of both Lake Eufaula Project personnel and contract personnel for labor and by the use of both government-furnished materials and contract-furnished materials. Lake Eufaula Project rangers constructed planting beds (water troughs bound by 2- by 4- by 50-ft boards) for the coconut fiber mats containing sprigged wetland plants. Plants in these mats also were irrigated and nurtured by the rangers at the nursery site. Then, contract personnel took over. They moved the mats to the sites by rolling them into large rolls and they cut them into 5- by 6-ft pallets at the site and staked and wired them to the substrate after they built the breakwater systems.

A purchase order method of contracting was used since it lends itself to the use of brief sketches and specifications and can be implemented quicker than the use of a full contract that often includes more expensive designs. This was necessitated by the small, low budget and the limited amount of time in which to accomplish the work.

The purchase order mentioned above was issued in September 1992 to complete the two test sites and was for $16,333. One modification was issued for an increase of $750 which extended the gabions on the sides of each site by 42 feet. The contractor using four individuals, two small loaders (one front-end loader and one bobcat loader), hand tools, and power saws completed the two test sites in about two weeks. The approximate cost of government furnished materials, construction contract, plus contract construction supervision is provided below.

The cost for the construction of the breakwater using the coconut fiber rolls is a higher cost per foot than the branchbox breakwater made from the dead branch bundles. If the cost were considered equal, the average cost per square foot (each test site is approximately 100' long with 2,200 square feet of area for each site) would be $6 per square foot. It should be noted that this cost will decrease with a larger operational area.

Item	Approx Cost ($)
Construction Contract (total)	$17,083
Government Furnished items:	
Gabions (260' of 1'x 3' baskets)	1,040
Treated Post (100 4" x 10')	800
Rock (50 tons of 6" rock)	400
Coconut fiber rolls (20-ft, 12" dia. rolls, price includes shipping)	4,300
Coconut fiber mat (4 ea. 6- by 50-ft rolls, price includes shipping)	835
Materials for growing beds (estimated)	250
Supervision and Admin of Construction Contract	2,000
Total Estimated Construction Cost	$26,708

Evaluation During Lake Operation

Since completion of the project in mid-October 1992, Eufaula Lake has experienced severe flooding. However, the lake was lowered between floods in March 1993 and the project was qualitatively evaluated then by representatives from WES and TD. The general observations given below are preliminary in nature and are not conclusive of success or failure at this point in time.

Plantings. The switchgrass was alive and beginning to grow. The species, wherever it was planted, had almost a 100 percent survival rate. The softstem bulrush and common reed, wherever it was planted, survived and was beginning to "green up." The cattails had been eaten by or cut off by local wildlife (probably muskrats). Generally speaking, all of the species had survived flooding (completely submerged) from November 1992 until early March 1993.

Branchbox Breakwater. One segment of the structure had disappeared. That was the segment that blocked the wave action from the opening in the breakwater. As seen from the sketch in Figure 1, an opening was left in the branchbox breakwater to allow ingress and egress of fish and other organisms. The failure of this segment was attributed to posts not being driven down an additional 2 feet which was an oversight during development of the plans. This, in turn, caused both the posts and the branchboxes to be loose and unstable. All the remaining segments of the structure were stable.

Coconut Roll Breakwater. The coconut rolls had experienced considerable damage. The coconut fiber rope mesh had broken allowing the fiber in several rolls to wash ashore. Under the extreme wind-wave environment in this area, coconut rolls that have polyethylene mesh webbing surrounding them should have been used. This type of mesh material would have held the coconut fiber in place. Plans are being developed to replace the 20 coconut rolls

with the polyethylene webbing rolls in the summer of 1993. This will allow the test to continue at this site.

Sedimentation. Within the first three days after the breakwaters were in place, there was a significant buildup of sand within the confines of each breakwater site. When the sites were evaluated in March, sand had completely covered the gabions extending up the sides of each site. The accretion of sand changed the shoreline morphometry to the point of moving it about 20 feet lakeward at the normal pool elevation.

Summary

Based upon the early evaluation of these two bioengineering test sites, the use of these erosion control methods should be further tested. There is a growing demand by the public to revegetate the shoreline of our reservoirs with wetland plants for several reasons: habitat for wildlife and fisheries, improved water quality, lower costs, and several others. The traditional erosion control methods, such as riprapped revetments may not be excluded entirely, but they must be evaluated carefully along with bioengineering methods in an attempt to achieve cost-effective erosion control that is environmentally compatible. As bioengineering construction processes become more refined and efficiently implemented to use wetland plants to control erosion in this country, the cost will decrease. These two sites will continue to be evaluated.

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Plantation Establishment to Restore Bottomland Hardwood Wetlands: Past and Future Research at the Southern Hardwoods Laboratory, Dr. John A. Stanturf, USDA Forest Service, Southern Hardwoods Laboratory, Stoneville, MS

Introduction

Bottomland hardwood forests once covered vast acreages of the South. Flood control and drainage projects encouraged clearing the forests for agriculture. Clearing accelerated through the 1970s in the Mississippi Alluvial Valley (MAV). Today, however, there is a reverse trend toward reforestation of former cropland that regularly floods (Allen and Kennedy 1989). Reforestation was given further impetus by Federal incentives such as the Conservation Reserve Program, as well as public agency wetland mitigation and restoration projects (eg., Allen 1990).

The Southern Hardwoods Laboratory (SHL) is maintained at Stoneville, Mississippi by the Southern Forest Experiment Station, in cooperation with the Mississippi Agricultural and Forestry Experiment Station and the Southern Hardwood Forestry Research Group. Research at the SHL over the last 30 years has addressed many problems faced by land managers attempting to establish hardwood plantations in bottomlands associated with the major and minor tributaries of the Mississippi River. While much of this research was aimed at establishing and managing plantations for timber production, results can be applied to wetland restoration projects. Wildlife managers are particularly interested in hard mast species such as the oaks which can only be established on former cropland by artificial regeneration techniques including direct seeding or planting seedlings. Light-seeded species such as sweetgum, the ashes, and sycamore often become established naturally by wind and water dispersal of their seeds. As direct seeding has been unsuccessful for light-seeded species, their seedlings must be planted.

The objectives of this paper are to review research on artificial regeneration of bottomland hardwoods conducted at the Southern Hardwoods Lab; to provide some general guidance in approaching a regeneration project; to point toward more detailed information through appropriate references; and finally, to indicate briefly current research on establishment of mixed species stands that approximate stand structure of natural forested wetlands.

Match Species to Site

For regeneration to be successful, species preferences and tolerances must be matched to site characteristics, in particular inundation regime. Relative flood tolerance of bottomland trees were summarized by McKnight and others (1981). Inundation regime is more complex, however, than whether a site

floods or not, and seedlings are more susceptible than older trees. Depth, time, and duration of flooding must be considered, as well as the state of the floodwater, particularly flowing versus stagnant (Hook and Scholtens 1978). Inundation regime is difficult and time-consuming to measure, and often natural regimes have been altered. An indicator of flooding regime is published in soil surveys. Local expertise, especially nearby landowners, may know of alterations due to drainage and other factors not reflected in soil surveys. In any event, a flood history for the previous five years, including duration, timing, and depth of water should be determined in order to select species. The choice of species should be guided by the upper, rather than the lower, level of flooding. Most flooding tolerant species can be planted on drier sites, but not the reverse.

Soil physical conditions, root aeration, nutrient availability, and moisture availability during the growing season are other important factors to consider in matching species to site (Stone 1978; Baker and Broadfoot 1979). Broadfoot developed two methods for evaluating sites based upon soil characteristics. One approach requires knowing which soil series are present and consulting either Broadfoot (1976) or recently published soil surveys which contain woodland suitability interpretations (Francis 1985).

A more complicated approach involves estimating site index, a measure of inherent productivity based upon a tree's height growth over time. This method is described in the guide to site evaluation for 14 commercially important southern hardwoods (Baker and Broadfoot 1979). Advantages of this approach, as described by the authors, include "(1)...accurate estimates of site index under any soil or site condition; (2) it can be applied throughout the southern hardwood region...; (3) it does not require identification of soil series; and (4) it provides guidelines for soil ameliorative treatments" (Baker and Broadfoot 1979). Disadvantages include the need for users to determine, or at least estimate, soil conditions such as texture, compaction, water table depth, organic matter content, and pH (Francis 1985). On the other hand, most soil scientists and many foresters are able to make field estimates of these properties that produce site index estimates of sufficient accuracy for most reforestation projects.

Site index is a useful guide to inherent productivity, but there is no hard and fast rule for applying productivity measures to judge reforestation potential for wildlife and other purposes. I suggest a rule of thumb that a site be at least at the minimally acceptable level set by Baker and Broadfoot (1979), which ranges from 54% to 63% of the maximum productivity level for a species.

Bottomland soils of silt loam texture generally indicate a moist, well-drained site. Clay textured soils usually indicate a low site periodically inundated. Medium-textured soils are suitable for most bottomland hardwood species, with three possible exceptions. Survival and growth of red oak species is limited by high pH (over 7.0), although Shumard oak does well over pH 7.5 (Kennedy 1984; Kennedy and Krinard 1985). In former cropland,

plow pans can occur at 8-12 inches depth that will limit root development, affecting survival, growth and windfirmess. This condition can be corrected by subsoiling prior to planting or direct seeding. On former agricultural land or engineered sites chemical toxicities (pesticide residues, mineral toxicities) or nutrient deficiencies may occur. These can be diagnosed by soil analyses and corrected. Clay soils tend to be very wet in winter and spring and very dry in mid to late summer, presenting fewer options for species selection. Green ash and Nuttall oak, both flood tolerant species, also do better than other species when available water is low.

Direct Seed or Plant?

Techniques for planting bottomland hardwoods are well developed. Direct-seeding may cost less than planting seedlings but has proven successful only for oak species and sweet pecan. If good quality seedlings are planted properly and cared for well prior to planting, the chances for successful establishment are high (Kennedy 1984; Kennedy et al. 1987; Allen and Kennedy 1989; Kennedy Inress). The following briefly compares planting seedlings and direct-seeding; for more information on specific techniques, consult the forthcoming reforestation manual by Allen and others (In Press).

Advantages of planting seedlings include a wider range of species. Direct seeding has only proven successful for oaks and other large seeded species. Nuttall oak has been the most reliable species, and greater success has been obtained with the red oak group as compared to the white oaks (Johnson and Krinard 1987). Almost all attempts at direct seeding light seeded species (ashes, sweetgum, and elms) have failed (Allen et al. In Press). Failures have been attributed to drought stress shortly after germination or to bird and rodent predation.

Another advantage of planting seedlings is that a wider range of sites and conditions can be tolerated. While extended post-planting flooding damages most seedlings, the taller planted seedlings may extend above floodwaters and survive. On the other hand, there is a narrower planting window in the South for seedlings. We recommend from late December at the earliest to early April at the latest. Direct seeding offers a wider planting window. Studies have shown that acorns can be planted essentially year-around, although weather conditions following sowing can be critical to survival. The best times for direct seeding are fall through spring (Johnson and Krinard 1987; Wittwer 1991). Because white oak acorns don't store well, they should be direct seeded soon after collection, in late fall.

The main advantage of direct seeding is potentially lower costs (Kennedy In Press). This comes about in two ways -- all the costs of growing and handling seedlings are avoided, and it's usually less time-consuming to plant acorns than seedlings. The major disadvantages of direct seeding are that the plants are in more vulnerable stages of development longer, so that the risk of poor survival and possible failure is greater. Competing vegetation may pose

more of a threat to new germinants, as oaks are notoriously slow to develop above-ground. Thus a reasonable germination rate is only 35% to 40%. Our recommendation is to sow 700 to 1000 acorns/acre on most sites. On sites that have lain fallow for a few years, are weed infested and likely to have high rodent populations, the rate should be higher -- 1200 to 1500 acorns per acre (Allen et al. In Press).

Hand Versus Machine Planting

Direct seeding and planting seedlings can both be accomplished by hand using very simple and inexpensive equipment. On formerly forested sites, hand planting or sowing are preferred as intensive site preparation is not required. Planting or sowing by hand is easy to do properly, and all too easy to do improperly. Seedlings should be planted deeply enough that the root collar is just below the soil surface. Large seeds such as acorns should be sown between 2 to 6 inches deep. Better germination and survival results when acorns are sown between 2 and 3 inches. Deeper sowing (3 to 6 inches) may be worthwhile when there is a danger of surface drying or rodent pilferage.

Mechanical planting and sowing is significantly faster on clean sites with slopes less than 10%. Modified agricultural planters have been used successfully for direct seeding, although some new equipment has been developed for acorns. A broadcast seeder has been used in trials in Louisiana (Allen et al. In Press). Aerial seeding has been shown in small trials to have potential, although more work needs to be done to optimize the delivery system and the method of burying acorns after sowing (Allen et al. In Press).

Future Research

Past research at the Southern hardwoods Lab concentrated on establishing hardwood plantations for growing timber crops. While most of our effort is now on natural regeneration, limited future research on artificial regeneration will concentrate on methods to establish mixed species stands that more quickly resemble natural forests. One easy modification of present technology is to plant in wavy lines, thereby avoiding the appearance of a plantation. Other modifications will probably be necessary in order to establish mixed stands with a canopy structure that approximates natural stands and that maximizes avian diversity.

In most reforestation projects in our area, hard mast producers such as the oaks and sweet pecan have been favored for their value to wildlife. Wind and water dispersal were relied upon to establish soft mast producers such as sweetgum, sycamore, the ashes, and the elms. While generally successful, sites that do not flood often and are more than 100 yards from a seed source may not seed in with light seeded species (Allen and Kennedy 1989).

Recommendations for establishing mixed stands have been to plant species with similar flood tolerance, soil preferences, and height growth rates. Such mixtures include cherrybark and Shumard oaks; Nuttall and overcup oaks; sycamore and green ash; sweetgum and water oak; and cypress, green ash, overcup oak, and Nuttall oak. Most plantings following these recommendations have been block plantings or single species rows. This species clumpiness, however, does not mimic natural conditions. In order to make recommendations for more "random" mixes, we are acquiring basic information on how species compete with each other during early stand development, especially after crown closure. One systematic spacing study, at Lake George, Mississippi, is illustrative of this line of research. Here we are looking at two spacings between individuals (6 and 9 ft), the proportions of three species (green ash, Nuttall and water oaks), and the effects of two soil types (Goelz 1991). This study allows us to determine the relationship between species proportion and productivity (stand growth in volume or biomass), and the relationship between size, distance, and species of neighbors on individual tree growth. Because of slow early growth of oak seedlings, they can easily be overtopped by green ash and other competitors.

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Selection and Evaluation of Plant Materials for Constructed Wetlands, Donald Surrency, Plant Materials Specialist, USDA Soil Conservation Service, Athens, Georgia

Abstract

The use of constructed wetlands to treat agricultural and municipal non-point sources of pollution, and their potential for treating animal wastes is a rapidly emerging biotechnology. The vegetative component is a major factor in the function of a constructed wetlands, yet there is limited technical information available on the selection of plants adapted for systems to treat agricultural wastes. To advance this technology to treat agricultural waste, more information is needed on plants that are adapted to different hydrological and substance conditions, physical and chemical parameters of the wastewater, tolerance of ammonia, pH, nutrient removal efficiency, planting densities by species, establishment methods and operating conditions. Since constructed wetlands is dependent on duplicating these factors and their interactions, an understanding of the ways they influence vegetation is important for proper species selection.

To expand the construct wetland technology the Americus Georgia Plant Materials Center is conducting plant materials evaluation in Alabama and Georgia to obtain more information on species selection. Technical information is being recorded on plants that are adapted to different hydrological and substrate conditions, planting specifications, and tolerance to ammonia waste systems. Plants were assembled and evaluated in constructed wetland systems treating wastewater from swine and dairy operations, catfish production ponds, a small municipality in southwest Georgia, and for residences.

Giant Cutgrass and giant bulrush were the best wetland plants for constructed wetlands based on data obtained from four years of field testing. They are more adapted to the higher nutrient concentrations that occur in the first cell of a constructed wetland system, than other tested entries.

Giant Cutgrass (*Zizaniopsis miliacea*) an excellent aquatic plant for transplanting into constructed wetlands. Consistent survival and rapid growth.

Giant Bulrush can be used in constructed wetlands, in the south and southwest, because it is a vigorous rhizome producer and has production into the winter months when many of the warm season wetland plants have become dormant.

It constructed wetland studies at Eatonton, Georgia, Giant Bulrush survived ammonia concentrations greater than 200 mg/l for extended periods. (EPA test) The main characteristics of selecting plants for constructed wetlands to

treat animal waste water is its ammonia tolerance. At the same location, cattails were killed by the high ammonia concentration.

The Americus Plant Materials Center has released giant bulrush and giant cutgrass as selected ecotypes (*new varieties*) for use in constructed wetlands to treat agricultural non-point source pollution and for the creation and restoration of wetlands. The variety names are WETLANDER Giant Cutgrass and RESTORER Giant Bulrush.

Introduction

Although the ability of aquatic plants to improve the quality of water in which they are grown has been known for over twenty-five years, only recently has this phenomenon been accepted as a cost-effective means of treating wastewater.

As the role of the Soil Conservation Service in water quality activities become more certain, vegetation (plant materials) is likely to emerge as a major tools to use in soil and water conservation to address water quality problems. The plant materials program involvement will include the evaluation of promising plant materials for improving water quality and to ultimately provide the opportunity to expand the number of plant species that are suitable for agricultural and industrial uses for pollution control.

Research information on the number and kind of plant species that are recommended for constructed wetlands is very limited. There is limited information available on sources of plant species to use in systems addressing constructed wetlands. Plant material species and sources for constructed wetlands for both agricultural and non-agricultural use are also limited. In most cases, the plant materials that are being used for constructed wetlands are collected from local naturalized stands, or purchased from nurseries and shipped to areas where the adaptation and performance of the plants is not known. Information on plant sources, planting and establishment methods, spacing, substrate and water level requirements is not available to users.

Raw livestock wastewater sampled from animal waste lagoons considerably higher concentrations of biological oxygen demand (BOD_5), 100-200 mg/L of ammonia and 75-150 mg/L total phosphorous than municipal wastewater. The low cost, yet effective, use of constructed wetlands in assimilating agricultural wastewater has shown much promise. There is concern, however, that the high concentration levels of nutrients, especially ammonia, in agricultural waste systems may exceed the tolerance level of most aquatic plants. Ammonia is a factor that must be considered in plants that are used in constructed wetland cells, especially, cell one in the multicell constructed wetland. The plants were evaluated in swine dairy operations that had ammonia levels that have reached or exceeded 100 mg/L.

The vegetative component is a major factor in the treatment processes that occur in constructed wetlands. There is a complex symbiotic relationship between the plants (root system), microorganisms, substrate, soil and the nutrients in waste water. It is important to understand how a particular species react to wetland conditions before that species can be recommended for use in constructed wetlands. Wetland plants use a number of adaptive strategies to with stand varying edaphic and hydrologic conditions. For example, wetland plants have air spaces (aerenchyma) in roots and stems that allow the diffusion of oxygen from the aerial portions of the plant into the roots.

Natural processes, which include the symbiotic relationship between plant roots and microorganisms, are the most promising biotechnology being developed today for agricultural and municipal wastewater treatment. One of nature's most powerful tools for cleaning the environment is through the synergistic reactions taking place between plants and microorganisms. Plants excrete substances from their roots (*exudates*) that determine the number and type of microorganisms that can live on and in the immediate vicinity of the plants roots. The area influenced by plant root exudates is called the "rhizosphere."

Microbial populations in the water column, attached to vegetative and other substrates and within the soils modify hydrocarbons, metals, pathogens, and nutrients loads causing precipitation of some pollutants and recycling with subsequent settling out, of others. Not only does a dense stand of wetlands vegetation provide a large surface area within the water column for microbial attachment, but the radial oxygen loss from wetlands plant root structures create a substantial aerobic environment for microbial populations within the substrate.

An assembly of a large number of aquatic plant species were collected and assembled for testing and evaluation in a typical swine and dairy operations, and a small community municipal constructed wetland in 1989 and 1990. Plant materials were selected on the criteria that was identified as very necessary characteristics for the operation of constructed wetland systems and for animal waste water treatment.

There also exists the need for targeting best management practices (BMP) and monitoring the success of their implementation. The cooperative interagency demonstration projects in Putnam County, Georgia and Sand Mountain, Alabama are an evaluation of a selected BMP (constructed wetlands) utilized to capture discharge from overload lagoons. More than 20 different local, state and federal agencies are participating in the project and each are responsible for implementing the project objectives that are considered common to the agency.

Objectives

The main objectives for conducting an evaluation of aquatic plants for constructed wetland system are:

a. Assemble and conduct initial evaluations (screening) of a large number of aquatic plant species that have characteristics that are essential for growth and survival in CWS.

b. Determine the optimum plant spacing, establishment methods and constructed wetland environment for agricultural waste-water treatment.

c. Determine the plants that are adapted to the conditions and constructed wetland environment for agricultural waste-water treatment.

d. Determine the symbiotic relationship that exists in the treatment of the waste water and the role that the plants, substrate, microorganisms, root systems and other parameters have on the treatment processes and retention time.

e. Determine the fate of nutrients and other contaminants in the constructed wetlands.

f. Determine the O & M requirements to maintain the vegetation in the CWS over time.

g. Determine the effect of high nutrient concentration on survival and plant growth.

Study Areas

Sand mountain experiment station, Crossville, Alabama

The Sand Mountain area (Jackson, Marshall, and Dekalb Counties) of northeastern Alabama has been identified by the Alabama Agricultural NPS Task Force as the tip priority watershed in Alabama. The 626 mile are has approximately 3,000 farms, 12,000 cattle, 12,000 swine, 6.8 million poultry and 65,000 acres of cropland eroding at greater than twice tolerance. Water supplies, local tributaries, and Guntersville Lake are severely impacted by sediment, nutrients, agrichemicals, and bacteria.

The Auburn University Agricultural Experiment Station on Sand Mountain operates a swine farrowing and feeding operation of 64 sows and 175 finishing pigs. Swine waste at the Sand Mountain Agricultural Experiment Station receives primary treatment in two lagoons that are expected to reduce BOD_5 by 60 percent.

The design and construction for the agricultural evaluation/demonstration constructed wetland system was performed by TVA in 1988-89. The operation, monitoring and valuation of plant materials is conducted cooperatively with the Soil Conservation Service, Auburn University, Alabama Department of Environmental Management and TVA. The CWS consists of ten cells, five primary and five secondary that was ideal for conducting initial evaluations of different plant species. The cells are 25 feet wide and 165 feet long. The large number of individual cella provides for test/evaluation plots with different emergent plant species. This is a joint project with the Agricultural Experiment Station Auburn University, the Tennessee Valley Authority, and the Alabama Department of Environmental Management. Five pairs of wetland cells have been installed to treat the effluent from a swine lagoon. A mixture of wetland plants is being used in the cells. The Americus Georgia Plant Materials Center is evaluating the aquatic plants to determine those best for constructed wetland use. SCS provided 16 soil water lysimeters to evaluate the potential for seepage beneath the bottom of the cells. In addition, SCS is providing flow monitoring equipment to assist in an evaluation of a mass balance of nutrients and organics through one pair of cells.

Currently the lagoon effluent is diluted with fresh water from a farm pond; gradually the strength of the waste will be increased to determine if the plants can survive the high levels of ammonia in the undiluted lagoon water.

One complete cell system, primary (REP 1) and secondary (REP 2) was used to conduct the initial evaluation of sixteen species or varieties of aquatic plants. (Table 4) Halifax maidencane *Panicum hemitomon*, cattail *Typha latifolia*, prairie cordgrass *Spartina pectinata*, smooth cordgrass *Spartina alterniflora*, common reed *Phragmites australis*, giant cordgrass *Zizaniopsis miliacea*, southern bulrush *Scirpus californicus*, giant bulrush *Scirpus validus*, four accessions of water chestnut *Eleocharis dulcis,* canna lily *Canna flaccida*, pickerelweed *Pontederia cordata,* elephant ear, or wild toro *Colocasis esculenta*, blueflag iris *Iris virginica*, giant reed *Arundo donax*, arrowhead *Sagittaria lancifolia* were planted in 1989. Fifty plants of each species were planted on 3x3 centers with hand dibbles in May, 1989.

Piping in this system provides for variable application rates to each plot and water level controls within each plot. Substrate throughout the system is native soil.

Ground water monitoring wells were installed up gradient and down gradient from the constructed wetlands. Prior to loading samples were collected for determining background water quality Auburn University and TVA are providing technical guidance to complete this project objective. Results to date indicate high levels of removal of nitrogen (>90%), phosphorus (78%), biochemical oxygen demand (>90%), and total suspend solids (>90%). Bacterial levels have been significantly reduced but still exceed standards.

The lysimeters, installed at two different depths beneath the bottom of four cells, indicated that virtually no nutrients or bacteria are migrating downward.

Putnam County, Georgia

In 1987, the Piedmont Soil and Water Conservation District identified a potential problem with animal waste disposal around Lake Sinclair and Lake Oconee.

Dairy farming is widespread in the Georgia Piedmont. Water use for a typical dairy (150-200 head) amount to approximately 10,000 gallons/day for washdown of milking facilities. Wastewater from these operations is captured in lagoons which are intended to be a discharge system. Although periodic pump-out to prevent solids overload is an integral maintenance feature necessary for lagoons, prohibitive costs (-$6,000) for this service has precluded its occurrence. In addition to costs, inadequate pumping procedures have resulted in many lagoons becoming overloaded with solids, and thus, continuously discharging to adjacent water bodies.

The site of this demonstration/evaluation project lies in Putnam County near Eatonton, Georgia. Constructed wetlands have been installed at two dairy operations. One dairy, the McMichael Dairy, also has a newly constructed lagoon that was completed at the time the wetlands were installed.

The Key Farm, which is in close proximity to Lake Sinclair, has had a lagoon in place for several years. Both dairies have tributaries that drain into Lake Sinclair. Since the McMichael wetlands and lagoon are still in developmental stages, monitoring efforts are primarily directed toward the Key Dairy. As a result, this report will reflect findings of evaluation efforts related to the Key Dairy.

Putnam County, Georgia contains many of the states dairy herds. Because of the great number of dairy operations and their subsequent pollution potential, Putnam County was chosen as a test site for evaluating aquatic plants for constructed wetlands.

A three (3) cell constructed wetland (surface flow) at the Howard McMichael Dairy in 1990. The cells were planted as described below in 1990.

Cell 1 - Bulrush *Scripus californicus*
Cell 2 - cattail *Typha latifolia*
Cell 3 - Halifax maidencane *Panicum hemitomon*

Cell Size: 42' x 225'
Spacing: 3 ft. centers
Substrate: natural soil
Planting Methods: Tree dibble and a tractor drawn tree planter

Cell number two (2) at the McMichael Dairy contained a collection of cattails, twenty five (25) plants each from twelve states. The collection was made to determine if differences existed in cattails from a large geographic area.

Cell Size: 42' x 300'

A three (3) cell constructed wetland was built in 1990 at the Richard Key Dairy. The planting plan for the cells are described below.

Cell 1 - cattail *Typha latifolia*
Cell 2 - bulrush *Scripus californicus*
Cell 3 - 'Halifax' maidencane *Panicum hemitomon*

Cell Size: 42' x 300'
Spacing: 3 ft. centers

Cell number three (3) contained 100 plants each of canna lily, pickerelweed, elephant ear, arrowhead, prairie cordgrass and blueflag iris planted along the edge in three (3) inches of water for aesthetics and beautification.

Animal waste lagoons were available for primary treatment and setting of solids at all locations. Quarterly water chemistry sampling of the constructed wetland system and lagoon was begun in July 1990. Although not a task for the original plan of study, monitoring of non-point source run-off from the ungrassed feed lots and holding areas have been included as a project task by EPA. Water chemistry parameters for the constructed wetlands are ammonia-N, nitrate-nitrite-N, Total Kjeldahl N, total phosphorus, total organic carbon and total suspend solids. Water level recorders were employed at weirs wetland system influent and effluent.

Ochlocknee, Georgia

The small south Georgia town of Ochlocknee located about 8 miles north of Thomasville, Georgia, population of 558, have had domestic waste water treatment problems. For many years the town relied on septic tank systems for sewage treatment for the houses, stores, mobile homes, and local businesses. However, septic tanks did not work properly because of the poorly drained soils that are not suitable for septic tanks. Constructed wetlands have low energy requirements, compared to the other processes that require much larger initial investments to design and construct, and have higher operational costs (personnel and energy). They will also need either mechanical aeration or liquid distribution systems.

A constructed wetland system for Ochlocknee consist of two-2 cell systems that are one acre each for a total treatment area of four acres. A one acre oxidation pond or lagoon provides initial settling of solids and some detention prior to being discharged into the constructed wetlands. Construction was completed in 1990 and the aquatic plants were established in June and July of 1990.

The planting plan provided for giant cutgrass *Zizaniopsis miliacea* to be planted in the first third of the cell, cattail *Typha latifolia* the second third and

maidencane *Paincum hemitomon* in the last third of the cells. Wetland plants were obtained from USDA-SCS plant materials centers, USDA-ARS plant introduction stations, commercial nurseries and collected from local stands. The wetland plants were planted on 3 ft. centers with a tree dibble and a tractor drawn tree planter in June 1990. Water level was designed to be maintained at six (6) inches.

Monthly water chemistry sampling of the constructed wetland was begun in 1990 by the Georgia Department of Natural Resources, Environmental Protection Division. Water chemistry parameters are ammonia, dissolved oxygen, BOD_5, suspend solids, pH and flow. The data for the Ochlocknee constructed wetlands was obtained from GA.EPD.

Analysis of water chemistry at the Ochlocknee constructed wetland revealed a significant reduction of ammonia, BOD, total kjeldahl nitrogen and total suspended solids. Dissolved oxygen and pH levels from the wetlands were better than the receiving stream. Therefore, discharge from the wetlands improved the quality of water in the receiving stream.

Alabama A&M University, Huntsville, Alabama

A constructed wetland has been installed at a swine unit of a limited resource farm. SCS engineers provided design and construction assistance and the SCS Plant Materials Center provided the plants. Alabama A&M and SCS developed a sampling and monitoring plan to evaluate the effectiveness of this wetland in treating the swine lagoon effluent. Bulrush *Scirpus californicus* was selected for planting in the constructed wetlands because it has been proven to be adapted to wastewater consisting of high concentrations.

Catfish farm, Hale County, AL

A constructed wetland was installed to recycle water from a commercial catfish pond. The water is pumped to the wetland and the effluent returns to the catfish pond. The objective is to reduce nutrient and organic loads and thereby reduce algae production which produces off-flavor in the fish.

This is a joint project of Auburn University, a local catfish producer and the Soil Conservation Service. Plant materials consists of giant bulrush, *Scirpus californicus*, giant cutgrass, *Zizaniopsis miliacea* and 'Halifax' maidencane, *Panicum hemitomon*. 'Halifax' maidencane is a released variety from the SCS Coffeeville Plant Materials Center for constructed wetlands and restoring and creating wetlands.

Nutrient tolerance

Physical and chemical parameters of the lagoon wastewater can affect the survival and growth of wetland plant species. The Putnam County Georgia constructed wetland sites provided the opportunity to determine the aquatic plants (giant bulrush and cattail) response to high nutrient concentrations of waste water that were recorded in the top cells. The discharge of effluent from the lagoon to the top cells had nutrient concentrations, that averaged 160-170 mg/L of ammonia. Giant bulrush plants did tolerate the high ammonia concentrations in the top cell. It is important to know the nutrient concentration that exist in the lagoon to be able to select the most tolerant plant species. This is an important planning consideration for developing plans for constructed wetlands that will be used to treat dairy, swine, and poultry waste water. It is important and essential to collect samples of the lagoon effluent and determine BOD, pH, ammonia and suspended solids in older lagoons as part of the planning process. A multi-cell system of 3 or 4 cells in series provided the best reduction of effluent from the animal lagoon. Therefore, constructed wetlands must be a planned component of the total animal waste treatment system.

Plant section for multi-cell constructed wetlands with high ammonia concentration based on three years of evaluations consists of the following:

Cell 1 - Bulrush - *Scirpus californicus*
Giant cutgrass - *Zizaniopsis miliacea*

Cell 2 - Bulrush - *Scirpus californicus*
Giant cutgrass - *Zizaniopsis miliacea*
Cattail - *Typha latifolia*

Cell 3 - Bulrush - *Scirpus californicus*
Giant cutgrass - *Zizaniopsis miliacea*
Cattail - *Typha latifolia*
Maidencane - *Panicum hemitomon*
Canna Lily - *Canna flaccida*
Pickerelweed - *Pontederia cordata*
Prairie Cordgrass - *Spartina pectinata*
Blue Flag Iris - *Iris virginicus*
Arrowhead - *Sagittaria lancifolia*
Phragmites - *Phragmites australis*

Planting methods

The constructed wetland sites in Putnam County, Georgia consisted of large cells that were located in the piedmont section on upland soils. The sites were dry and were easily accessible with a tractor drawn tree planter. The planter worked extremely well and successfully planted cattail, bulrush, giant cutgrass, pickerelweed, canna lily and elephant ear at the desired depth and spacing.

Maidencane rhizomes were also planted with the tree planter. The wet sites located in Ochlocknee, Georgia and Sand Mountain, Alabama were successfully planted with a hand dibble. Plant materials were planted deep enough to prevent propagules from floating out of the planting hole. Planting densities vary with target operating dates and species used. In the southeast, a 3-4 ft. spacing for most herbaceous plants provide good stand densities in about 4-6 weeks, with excellent coverage in 8-10 weeks. Giant cutgrass is a vigorous spreader and propagates easily from the nodes can be planted on a 6 ft. spacing and obtain a dense stand in about 6-8 weeks. Giant cutgrass and giant bulrush produced 20-30 new stems and 5-M spread in 4 weeks after established in Alabama.

Post-planning water level management

Proper water depth and its careful regulation are the most crucial factors for plant survival during the first year after planting. New plantings can fail because of mistaken concepts that wetland plants need or can survive in deep water. Small, new plants lack extensive root, stem, and leaf systems with aerenchyema channels to transport oxygen to the roots. Consequently, flooding can cause more problems for wetland plants during the first growing season than too little water, especially if the wastewater has low dissolved oxygen content. After the constructed wetland cells were planted the substrate was saturated with pond water to about one inch for 4-5 weeks. After the 6th week when the submergent plants showed new and vigorous growth, water levels were slowly an gradually increased to support erect, upright growth forms. The plants were allowed to become established before the wastewater effluent from the animal waste lagoon was discharged into the constructed wetlands. The lagoon effluent was applied to the existing water in the cells to acclimated the plants to the increased nutrient load. It is absolutely essential that the stems and leaves of desirable species are above the water surface to avoid drowning new or even older established parts. Water level should never be lowered to the extent to expose plant roots. Dry cell conditions, or not enough water will result in poor survival.

It is important to the survival of the vegetation to design systems with life or no slope on the substrate and easily maintained water control structures that precisely regulate elevations. Water level management must create very similar water depths/or duration of flooding throughout the newly planted area, and must precisely maintain that level despite fluctuating inflows. Many new plantings have been lost because stormwater inflows could not be discharged rapidly enough to avoid overtopping and drowning small plants. The inability to drain the entire area on schedule due to undersized control structures or uneven substrates will cause spotty areas of poor growth and mortality.

Results and Discussion

Plant evaluations

Table 1 shows that the percent stand was the best for giant cutgrass, maidencane, giant cutgrass, pickerelweed and cattail at the Sand Mountain Experiment Station. Giant reed *Arundo donax* could not tolerant the six (6) inch water level that was maintained in the constructed wetland cells.

Giant cutgrass, maidencane and cattail stands were good at two other sites in Alabama and Georgia. Giant cutgrass is a very aggressive plant in the cells. It usually crowds out other species with prolific growth, spread and vigorous rhizomatous root system. This plant has never been evaluated for constructed wetlands but it appears to be extremely adapted to systems in the southeast. Water level adjustments up to twelve (12) inches did not affect its vigor, growth or survival. Based on the spread by rhizomes the first year this plant can be planted on six or eight foot centers and establish quickly. It also grows roots very easily and readily from the nodes when in contact with water and the substrate. Giant cutgrass survived winter low temperatures to -2 F recorded at the Sand Mountain Experiment Station in Alabama.

The plant materials dormancy Table 2, shows that giant bulrush, *Scirpus californicus* and *Scirpus validus* were not affected by low temperatures during the winter as other aquatic plants. In December and January 1990-92 new growth or tillers were observed below the water level. The stems were green and vigorous also. Based on the role that plants play in constructed wetland environment the winter dormancy of giant bulrush is a very important characteristic. Most of the other aquatic plant materials were burned by the first or second heavy frost. The first killing frost usually occurs around October 15 to November 1 in project areas. Pickerelweed, elephant ear, canna lily, and arrowhead are the first to burned back from the frost damage at these locations.

Table 3, recommended plant spacing for constructed wetlands is based on three years of data obtained by evaluating the plant growth and rate of spread in actual constructed wetland conditions in Alabama and Georgia.

The initial plant evaluations in 1989-92, Table 4, shows that the best aquatic plant materials at the Sand Mountain Alabama site are cutgrass, Halifax maidencane, giant bulrush and arrowhead.

Cattails *Typha latifolia* were not as vigorous the third growing season as were observed the first and second growing seasons. Cattails have been recommended for constructed wetlands in municipal systems, but it was not the best plan based on performance for agricultural constructed wetlands.

Giant bulrush *Scirpus californicus* and *Scirpus validus*, giant cutgrass *Zizaniopsis miliacea*, 'Halifax' maidencane *Panicum hemitomon*, pickerelweed *Pontederia cordate* and arrowhead *Sagittaria lancifolia* are the best wetland plants

to use in constructed wetlands for treating waste water from dairy and swine operations and for municipal constructed wetland systems. Cattails were defoliated by army worms in the summer of 1991 at Sand Mountain, Eatonton and Ochlocknee.

Cattail *Typha latifolia* performed well as a standard of comparison for the other plant accessions, but it was susceptible to insect damage, and the vigorous stand appeared to be stressed when subjected to high ammonia levels in the top cell.

Although this paper reflects only interim results, it appears that constructed wetland provide a positive approach to controlling overflows from dairy lagoons. Constructed wetlands for animal waste water contributed to a >90% reduction of total nitrogen and >80% reduced of total phosphorus. In addition, a significant reduction in both nutrient and solids loading to area streams is occurring.

Water chestnut *Eleocharis dulcis* stands were significantly damaged by muskrats at the Sand Mountain Alabama site. Water chestnut receives tremendous competition by invaders over time. It does not provide quick spread, and it's growth is a major limitation.

Elephant ear *Colocasis esculenta* will not recover the second growing season in constructed wetlands when water levels are maintained at six (6) inches during the dormant season. However, it will recover around the shallow edges where it is best suited to provide plant diversity.

Blue flag iris *Iris virginica* was planted to provide diversity, aesthetics and possible beautification to the constructed wetlands in urban areas. The plant grows in three to six inches of water and can tolerate high nutrient levels that area usually common to the second cell in animal waste water systems. Canna lily, arrowhead and pickerelweed also produced beautiful yellow, red, orange and white flowers.

Conclusions

RESTORER Giant Bulrush (*Scirpus californicus*) proved to be an excellent aquatic plant for transplanting into constructed wetlands. Consistent survival and rapid growth response after transplanting was documented at all field planting study sites. Growth densities allow for good coverage in substrates usually found in most of the major Land Resource Areas in Alabama and Georgia, including the Blackland Prairie. Bulrush has desirable-growth pattern for constructed wetlands. It is a vigorous rhizome producer and has production into the winter months when many of the warm season wetland plants have become dormant.

In constructed wetland field planting studies at Sand Mountain, Alabama, and Eatonton, Georgia, **RESTORER** Giant Bulrush survived ammonia

concentrations greater than 200 mg/l for extended periods. (EPA Data) **RESTORER's** tolerance to ammonia, which is a serious problem in treating effluent makes it a superior plant to use in the first cell of the constructed wetland system. At the Eatonton, Georgia study site, cattails were killed in the first cell as a result of the high ammonia concentration. Stem counts at two sample locations, Greensboro and Huntsville, Alabama revealed significant increases. Site 1 (Greensboro) was transplanted with three stem plants in June, 1992, and steadily increased to 20 stems in five weeks. Surface coverage at site 1 was significant all the growing season. Site 2 (Huntsville) was transplanted with three stem planted in May, 1992, and they increased to 25 in six weeks. The vigorous rhizome spread and tillering indicates that **RESTORER** can be planted on six feet centers and provide good surface coverage the first growing season. Therefore, from an economic point of view, it costs the farmer, or other user about 50% less to plant **RESTORER** than to plant cattail which requires a spacing of three feet centers.

The Sand Mountain wetlands have been efficient in the reduction of nutrients in swine lagoon effluent. Ammonia and nitrogen reduction was more than 95%. BOD_5, total phosphorus and suspended solids were reduced 91%, 78%, and 92% respectively.

The U.S. Environmental Agency (EPA) conducted the analysis of water chemistry data at the Eatonton, Georgia site prior to installation of the constructed wetlands at the Key Dairy. The data revealed elevated nutrient concentrations during active lagoon discharge from this overloaded dairy lagoon. At the time total nitrogen and phosphorus concentrations exceeded 160 and 35 mg/l respectively. Since the installation of the constructed wetland, the frequency of solids and nutrients loading to the receiving streams have been reduced. In addition, comparisons of water chemistry data from the animal waste lagoon and constructed wetland indicate a greater than 90% and 80% removal of total nitrogen and phosphorus, respectively. RESTORER survived winter temperatures of -2 F recorded at Sand Mountain Alabama Experiment Station. It maintains good vigor and green color late in the winter after most warm-season wetland plants have become dormant. Observation made in February of older stands in Eatonton, Georgia revealed only the top 25-30% of the plant stems were damaged by the winter temperatures. The bottom portions were still relatively green. New tillers were also observed in late winter below the water level.

Ager and Kerce (1970) documented the growth of giant bulrush (*Scirpus californicus*) in deep marsh areas and submerged vegetation zones which were only periodically exposed. This was probably due to the ability of bulrushes to transport photosynthetic oxygen from the stems to the root system, (Langeland, 1981) and adaptation inherent in many aquatic vascular plants. Superior ammonia removal efficiencies of bulrushes were attributed to their better oxygen translocation ability from the shoots to the roots (Gersherg, 1986).

RESTORER Giant Bulrush have tall hollow stems that are about 1.5 inches in diameter in mature stands. These tall, large diameter stems could be a

dominant characteristic, that provide a larger area to conduct a substantial increase in the volume of oxygen and other atmospheric gases down into their roots. Because the outer covering on the root hairs are not a perfect seal, oxygen leaks out; creating a thin film or aerobic region, (the rhizosphere) around each and every root hair. The larger region outside the rhizosphere remains anaerobic. The aerobic region surrounded by an anaerobic region is crucial to transformations of nitrogenous compounds and other substances.

RESTORER can be transplanted easily with a hand tree dibble or a tractor drawn tree planter for planting larger constructed wetland sites. Bare root and container grown material can be used for transplanting. **RESTORER** will be commercially available in 1994.

WETLANDER Giant Cutgrass (*Zizaniposis miliacea*) an excellent aquatic plant for transplanting into constructed wetlands. Consistent survival and rapid growth response after transplanting was documented at all field planting study sites. Growth densities allow for good coverage in substrates usually found in most of the MLRA's in Alabama and Georgia, including the Blackland Prairie. **WETLANDER** has desirable growth pattern for constructed wetland. It is a vigorous rhizome producer and has production into the winter months when many warm season wetland plants have become dormant.

In constructed wetland field planting studies at Sand Mountain, Alabama and Eatonton, Georgia. **WETLANDER** Giant Cutgrass survived ammonia concentrations greater than 100 mg/l for extended periods. (9EPA Data) **WETLANDER's** tolerance to ammonia, which is a serious problem threatening effluent makes it a superior plant to use in the first cell or second of the construed wetland systems. At the Eatonton, Georgia study site, cattails were killed in the first cell as a result of the high ammonia concentration.

WETLANDER can be transplanted easily with a hand tree dibble or a tractor drawn tree planter larger constructed wetland sites. Bare root and container grown material can be used for transplanting. **WETLANDER** will be commercially available in 1994.

Stem counts at two sample locations, Eatonton, Georgia and Sand Mountain, Alabama revealed significant increases. Site 1 (Eatonton) was transplanted with two stem plants in June, 1991, in a constructed wetland cell at eight feet centers and the stems steadily increased to 15 stems in six weeks. Surface coverage at site 1 was significant and filled in all open spaces in the first growing season. Site 2 (Sand Mountain) was transplanted with two stem plants in May, 1989, and they increased significantly in six weeks. The vigorous rhizome spreads and tillering indicates that **WETLANDER** can be planted in eight ft. centers and provide good surface coverage the first growing season. Therefore, from an economic point of view, it costs the farmer, or other user about 50% less to plant **WETLANDER** than plants such as cattail that will require a spacing of three ft. centers.

The Sand Mountain wetlands have been efficient in the reduction of nutrients in swine lagoon effluent. Ammonia and nitrogen reduction was more than 95%. BOD_5, total phosphorus and total suspended solids were reduced 91%, 78% and 92% respectively.

WETLANDER Giant Cutgrass stands were excellent at constructed wetland sites in Alabama and Georgia. It is very aggressive in all cells and usually crowds out other species with its' profilic growth, spread and vigorous rhizomatous root system. Water level adjustments up to twelve (12) inches did not affect its vigor, growth or survival. Based on the spread by rhizomes the first year, this plant can be planted six (6) or eight (8) feet centers and established quickly. It also roots when in contact with water and the substrate. Wetlander can tolerate animal wastes. It also survived winter temperatures to -2 F recorded at the Sand Mountain Alabama Experiment Station.

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Constructed Wetlands in Alabama and Georgia		
Type	**Location**	**Year**
Swine	Sand Mountain, AL	1989
Dairy (2)	Eatonton, GA	1990
Municipal	Ochlocknee, GA	1990
Diary	La Grange, GA	1991
Diary	Jasper, GA	1991
Swine	Huntsville, AL	1192
Catfish	Greensboro, AL	1992
Residences (12)	Gunterville, GA	1922
Swine	Vienna, GA	planned 1992
Poultry	Gainesville, GA	planned 1993
Catfish	Greensboro, AL	planned 1993

Plants Evaluated 1989-1992
Maindencane ('Halifax')
Giant cutgrass
Prairie cordgrass
Common reed
Water chestnut
California bulrush
Bulrush
Arrowhead
Elephant ear
Pickerelweed
Blueflag iris
Cattail
Giant reed
Canna lily
Smooth cordgrass

A Paradigm for the Selection of Vegetation Effective in Phosphorus Removal for Restored and Created Wetlands, Lynn E. Zender, Civil and Environmental Engineering Dept., U.C. Davis, Davis, CA.

Introduction

One of the primary antecedent functions of a degraded wetland is likely to be nutrient removal. But, because most watershed now are subject to nutrient enrichment by nonpoint source pollution, to effectively serve as a 'nutrient sink', a restored wetland must be even more efficient at removing nutrients than when under the more pristine conditions of the past. As a result, even if restored soil and hydrology characteristics are not appreciably different from the original wetland, the historic vegetation of the area may not be the best choice of flora for system restoration. The higher nutrient load could result either in these species being succeeded by more nutrient-efficient plants, or in insufficient nutrient removal for downstream ecosystems. Therefore, the selection of species for a restoration site should not be an automatic one, but rather be a logical and natural outcome from the process of site review. That is, the 'best choice' of species is predetermined to a large extent by the goal(s) of the project and the particular site conditions, history, and ecological and tangential considerations (the 'site story'). The straying from this 'logical ecological' method will likely produce a project which is suboptimal.

Species selection is often carried out by gathering separate pieces of information together and evaluating them *em masse*. Such a process has an inherent susceptibility to incidental exclusion of key criteria because its random structure does not ensure that the criteria will be considered. The objective of this paper is to suggest an alternative method for species selection that is pyramidal and deductive in nature,and can therefore more readily assume inclusion of the factors of concern. The proposed approach is applied to the selection of plant species for maximum phosphorus (P) removal.

Methodology

Figure 1 shows a generalized schematic of the selection process. The method begins by identification of all key parameters that influence the project goal(s), and sequentially builds by, first, characterization of factors that influence the determination of these goal parameters (primary factors), and next, by consideration of factors that influence those primary factors (secondary factors), and so on as needed. Each component of the 'pyramid' favours (draws merits) or disfavours (draws demerits) a different candidate plant(s). A relatively greater value is assigned to those plants which result in the greatest movement of the system towards the goal. Plant species for which certain factors may not apply are assigned neutral values of zero for these factors. In

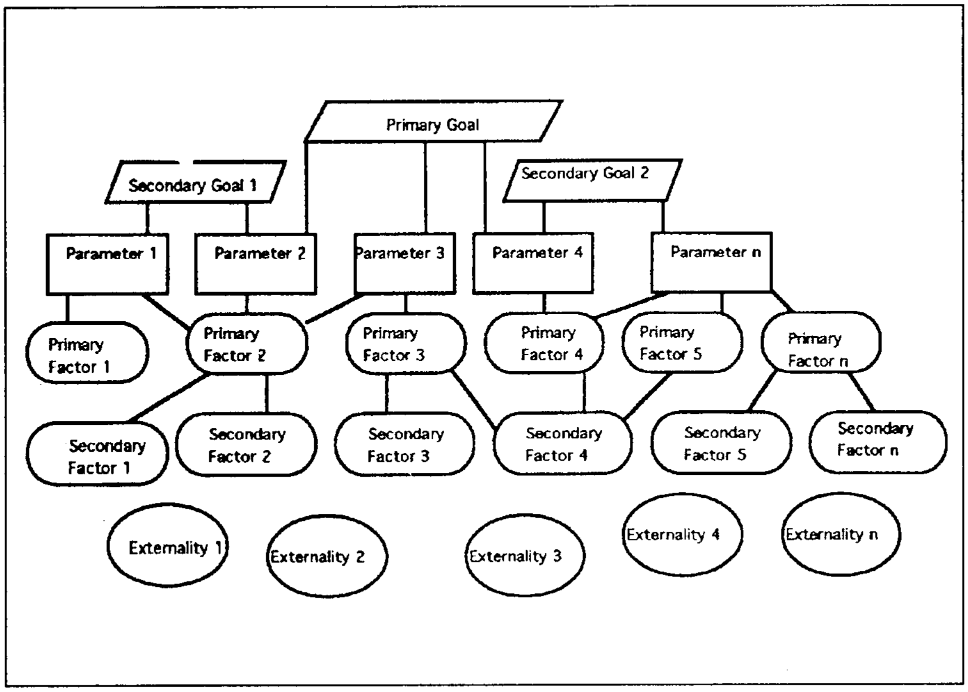


Figure 1. General schematic of Selection Pyramid

the end, P removal is 'optimized' by using the plants that contribute the most to the determination of the identified parameters (accumulate the highest number of merits).

The first step in the selection process is the identification of the project goal(s). The goal(s) should be stated in unambiguous terms, and involve only one theme. Naturally, most restoration projects involve more than one goal. The method is amenable to multiple goals by incorporation of these goals into a more highly branched pyramid, as shown in Figure 1. Emphasis is placed on primary goals by assigning a higher relative weight to the associated factors which determine them. In this way, plants selected will, at a minimum, be compatible with primary goal achievement but should also result in maximum attainment of secondary goals.

Next, the goal parameters are formulated. A parameter is a fundamental condition or process that partially, but directly, determines the value or relative condition of the goal. It is crucial to identify a complete set of parameters in order to take advantage of the benefits of this method. That is, assuming perfect knowledge of each individual parameter, the set of parameters must of itself wholly describe and determine the value or condition of the goal. It is in this way that inclusion of all key considerations can be assured. Each goal must have at least one parameter which determines it and is likely to have several. Different goals may have one or more parameter(s) in common.

Following the description of parameters, primary factors are named. These are factors *which plants are able to affect* and that help to determine the value

or condition of the parameters. There may be some initial confusion as to what exactly constitutes a parameter a opposed to a factor. A useful way to separate parameters and factors is to think of them as components of a model. Both factors and parameters may be used as inputs or determined in interim steps of the model. Yet it is only what are termed parameters here that would be used in the final arithmetic to calculate the model's output.

If needed, secondary factors are then listed. These cans be related facets of the primary factors or a breakdown of the primary factors into components more amenable to relative ranking. It should be noted that secondary factors are not necessarily more important than primary factors. In fact, their consideration can be central to optimal plant selection.

It is not necessary, nor even in some cases desirable, to weigh all of the factors equally. If formulated properly, the model should indicate a relatively greater importance of a factor by the absolute number of components in the preceding levels that depend on it. If the best information shows a significantly higher importance for a certain factor, then this factor should be weighed accordingly by increasing the associated number of merits. However, consideration of how good the plant information is, and how applicable it is to the particular project, must be considered when assigning weights, and should limit the maximum number of merits possible.

If there is not a significant enough difference in the number of merits among candidate plants, externalities should be considered and ranked as well. Evaluation of externalities should narrow the list to the number of plants desired. If more than one species is to be planted, interactions (i.e. competition) between the top candidate plants should be considered to determine the feasibility of planting them together.

It does not make sense to waste time evaluating plants which will not establish successfully. Therefore, the preliminary list of plants (the initial palette) should be composed of desirable species that are well established in chosen reference communities. In this way, reasonable establishment of any of the plants can be assured, and he selection model is based on specific suitability. Prior to the initiation of the ranking process, consideration of the operational feasibility may be useful. Prohibitive costs or lack of availability of some plants may eliminate one or more plant species from the initial palette.

Case Study

The selection procedure is applied to a planned constructed wetland project in Davis, California. Two hundred-thirty acres of fallow agricultural land will be converted to back to their historic function as a freshwater wetland. The wetland will treat urban stormwater and the city's secondary wastewater effluent before discharge to a 20,000 acre wetland restoration project in an adjacent flood basin. While wildlife enhancement and native species are hoped for at the Davis site, the primary function will be to serve as a buffer zone and to

provide water to the basin at nutrient concentrations near natural levels, so that this area can be restored to as near as possible it's original state.

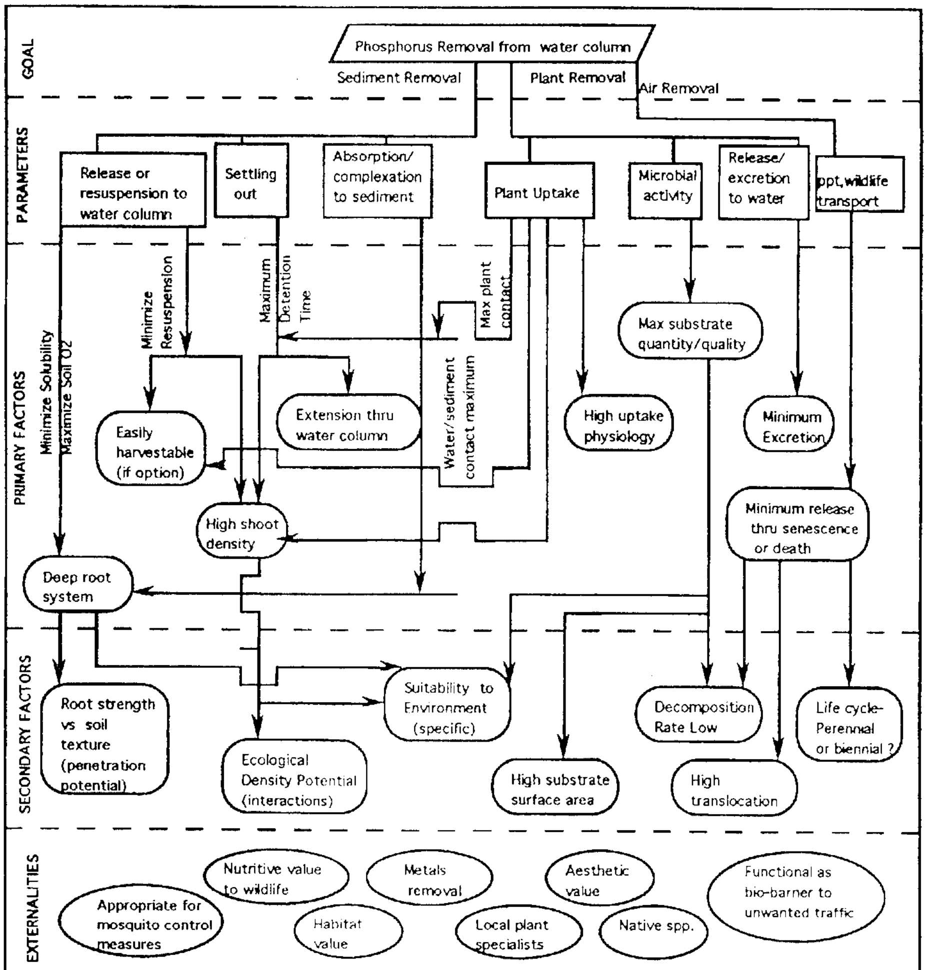
The initial palette was identified from the evaluation of three constructed wetlands in northern California (Arcata Wildlife Sanctuary, Mountain View Sanitation District, and Gustine Wastewater Treatment Wetlands). The candidate plants chosen from these wetlands were *Typha spp., Scirpus californicus, Sc. robustus, Lemna spp.,* and *Phragmites communis.*

Figure 2 shows the selection pyramid and ranking scheme. For simplicity, the single goal of P removal is used as an illustration. The parameters were chosen to cover all routes by which P leaves the water column (i.e. via sediment, vegetation, or air). Phosphorus removal in the sediment is due either to settling out on the soil surface or incorporation into the soil column by deposition, complexation, or absorption as the water moves through the sediment. Settled surface particles can eventually be complexed or absorbed as well so that there is some overlap in the parameters. The important point is that the two parameters together, along with the resuspension or release of sediment P (caused by desorbtion or solubilization from redox, chelation, or other chemical reactions), account for all of the ways in which P is associated with the sediment.

Likewise, with plant removal, P is transferred from the water by plant uptake (by particulate attachment to plants or by actual physiological uptake) or through plant release. Microbial activity is grouped with the plant removal parameter due to its rhizosphere and substrate association. Soil microbes outside the rhizosphere are included as a mechanism for absorption in sediment removal. Removal or addition of P form the air is not regained further due to the negligible effect that plants have on this parameter.

Overall, as reflected in the factors, the presence of plants may increase P removal in several ways: 1) hydraulically, by increasing the detention time, 2) physically, through filtration and by promoting quiescent conditions, 3) chemically, by aeration of the soil column, and 4) biologically, by release, excretion, or uptake of P compounds. Additional interactions, such as possible release of P chelators or organic acids for solubilization of soil P, are not included because they simply involve the transfer of P from soil to plant, and do not directly affect the P in the water column.

The scope of this paper does not allow detailed examination of each factor and its associations. Still, there are several general observations. First, it is important to note the difference between factors and parameters. The extent or amount of any of the parameters gives a partial accounting of the P budget. But, holding other conditions constant, factors by themselves, such as harvestability, plant density, etc., only indicate an increase or decrease in P removal. Second, note how the model indicates the relative importance of the factors by the number of parameters that are traceable from it. For example, high plant density is central to selection because it can be traced back to three separate parameters. Next, this pyramid is site specific. So, as an example, plant



RANKING

Ranking

Factors | Externalities

Pallete	deep roots	harvestable	shoot density	water depth extension	uptake physiology	subtrate quality	root strength	P release/excretion	penetration potential	substrate surface area	decomposition rate	life cycle	translocation	specific suitability	density potential	Subtotal	Mosquito control	Habitat value	Nutritive value	Plant Diversity	Total
Typha	+	+	+++	+	++	++	+	0	+	+	+++	0	0	+	++	19	0	0	0	—	16
Lemna	–	-	-	-	+++	--	0	0	0	-	-	0	0	+	++	1	++	++	++	++	9
Scirpus californicus	+++	+	++	+	+	++	+	0	+	0	++	++	0	+	+	18	0	+	++	+	22
Phragmites communis	++	+	++	+	++	+	0	0	0	0	+	0	0	+	0	11	0	+	+	+	14
Scirpus robustus	+++	+	++	+	+	++	+	0	+	0	++	0	0	++	+	17	0	+	++	+	21

Figure 2. Selection Pyramid and ranking for vegetation effective in phosphorus removal

uptake is not dependent on root depth in this system, whereas in less-nutrient rich systems it would be. In the high nutrient waters at the project site, the amount of P is not limited so that, regardless of the size or depth of its root system, an individual plant will be taking up the maximum amount of P that it needs given the site conditions. Also, because they were chosen from reference communities, all of the candidate plants are suitable to the site and can be assumed to establish reasonable dense stands. Therefore, the horizontal extension of the root system is judged to be of little consequence because the only significant means of increasing the volume of aerated soil, or water penetration along the root-bored paths, is an increase in root depth.

Figure 2 also shows the ranking of the candidate plants. These factors are complex and may involve far-reaching conseque which must be considered. For example, harvestability should take into account the availability of the specialized labor and machinery as well as the ecological soundness of the required technique. Also, the specific suitability to the environment and the ecological density potential both involve considerations, succession and secondary planting compatibility, and the extent that the success of the plants depends on planned or needed system management.

It is highly possible that available information on one or more of the factors is insufficient for proper evaluation. Full consideration of all aspects of a factor may be too time costly. If ranking is not possible, the factor should not be evaluated but left in the model as a reminder that final selection has been achieved with some unknown determinants. For example, very little study has been carried out on P excretion, but indications are that it is insignificant. Also, the amount of translocation and P release requires a site specific study to rank this factor accurately. Keeping in mind that these factors are unknown, the subtotal of merits does not indicate a significantly superior candidate plant. Therefore, externalities are also evaluated. Final selection is narrowed to the two *Scirpus* species.

Conclusion

In comparison to a selection process of random information assimilation, the foregoing 'logical ecological' method should better include all considerations related to phosphorus removal, and better exclude the superfluous considerations that do not impact removal. Furthermore, the procedure can be illustrated by a simple flowchart, and provides a formal and logical means to justify species selection to interested parties.

Geographic Information System (GIS) and Remote Sensing (RS) Applications in Habitat Quantification Methodologies: The Wildlife Habitat Appraisal Guide (WHAG), Amy Keeley[1], Jerry Skalak[2], and Joe Jordan[3]

Abstract

The Rock Island District of the U.S. Army Corps of Engineers (CENCR) uses the Wildlife Habitat Appraisal Guide (WHAG) to quantify existing wetland habitat resources. The values generated are subsequently used in the incremental analysis of habitat rehabilitation and enhancement alternatives and assessment of natural resource management strategies. Currently, this habitat quantification procedure is being accomplished by manually interpreting aerial photography and carrying out on-site team surveys. This approach is highly dependent upon professional judgments and relatively coarse measurement procedures. It also requires significant staff travel and field reconnaissance time.

This preliminary effort by CENCR to explore various opportunities to integrate the use of Geographic Information System (GIS) and Remote Sensing (RS) technologies with the WHAG quantification process suggests that values for WHAG model variables may be derived by processing imagery and querying other digital data sources. The use of these technologies potentially will eliminate assessment bias, increase measurement accuracies, and reduce field time and travel requirements. The employment of these technologies should further enhance the WHAG quantification process by supporting the assessment of additional model parameters and variables and the use of higher resolution and more current data. An overall improvement in model documentation will occur.

Introduction

The Rock Island District is one of three Corps of Engineers Districts that are planning, designing, constructing, and monitoring habitat rehabilitation and enhancement projects as part of the Upper Mississippi River

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System-Environmental Management Program (UMRS-EMP).[1] To maximize outputs from these aquatic and wetland restoration projects, habitat quantification and incremental analysis procedures are applied.

The Wildlife Habitat Appraisal Guide (WHAG)

The WHAG, a habitat quantification methodology jointly developed by the Missouri Department of Conservation and the Soil Conservation Service, is but one of many natural resource quantification and management strategy assessment methodologies. The WHAG is a habitat based model used to compare existing conditions with those projected to result from the implementation of specific site modifications and management alternatives.

Inputs to the WHAG model are based upon the measurement and assessment of broad land use categories (habitat types) and life requisite variables for multiple project area sample sites (each encompassing approximately 2,000 acres; a 2 mile diameter circle). Field sheets, developed for various species, are used in carrying out this assessment. Species selected for consideration may be specific management "targets" or representative of broader groups.

The WHAG generates two quantitative measures of habitat quality: Habitat Suitability Indices (HSIs); and Habitat Units (HUs). These values are based upon the habitat characteristics of the selected sample sites. Species characteristics matrices have been developed for various wetland dwelling species. Matrices for the "target" species or a species representative of a group that is the focus of management attention are used for field scoring selected sample sites. The HSI values range from 0.1 to 1.0. A critical limiting factor(s) may reduce the HSI value of a sample site to its lowest possible score regardless of other qualities of the sample site. Values for multiple sample sites may be averaged over the project area.

The UMRS-EMP consists of five program elements, two of which, the Long-Term Resource Monitoring Program (LTRMP) and Habitat Rehabilitation and Enhancement Projects (HREP) represent nearly 95% of the total program funding. The LTRMP element is managed by the United States Fish & Wildlife Service (USFWS) for the Corps of Engineers. The LTRMP is carrying out extensive data collection, resource monitoring, and research activities on a system-wide basis. The HREPs are being implemented in partnership with the five basin States (Illinois, Iowa, Minnesota, Missouri and Wisconsin) and the USFWS.

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[1] The UMRS-EMP was authorized in the 1986 Water Resources Development Act in part to address an ongoing loss of wetland and aquatic habitat throughout the Upper Mississippi River System. Funding for the UMRS-EMP is authorized through the year 2002 at an annual funding of $19.455 million. The Corps of Engineers is charged with overall program management and administration.

The HUs represent a composite estimate of useable habitat within a defined project area. They are derived from multiplication of available habitat acreages by the sample site or composite HSI value.

Initial comparisons of values for selected WHAG variables derived via the analysis of digital spatial data layers and processed imagery with those determined by field team estimation suggest that the quantification of existing habitat and the assessment of future-with and -without project scenarios can be facilitated and potentially enhanced by utilizing GIS and remote sensing technologies. As resolutions of remotely sensed data sets increase and more comprehensive thematic data layers become available, field work requirements for accomplishing project site habitat appraisals will be minimized and potentially eliminated. Also, the accuracy and thoroughness of site assessments will be improved.

It is suggested that the values for many, if not all, of the variables that are considered in accomplishing this habitat quantification methodology can be acceptably derived, directly or indirectly, through the use of GIS and RS technologies. Variables, such as emergent vegetation coverage or percent open water, can be readily quantified utilizing known pixel signatures and standard image processing techniques. Simple queries of readily available existing digital databases, such as forestry resource management polygons and land cover maps, can provide reliable values for several of the land cover variables considered in the WHAG.

Certain other variables may be derived by indirect means. For example, a value for the variable 'snags per acre' might be generated by assessing multiple factors such as tree stand age, stand composition, etc.

Input values for a majority of the WHAG model's variables should be attainable using standard GIS capabilities. A GIS can efficiently carry out complex analyses of spatial data such as: intricate Boolean queries involving multiple data layers, areal approximations of various land coverage classifications, and measurement of distances from one habitat type to another. The resolution and speed at which these and other analytical tasks may be accomplished is significantly greater than the current manual approach. Also, the ability to explore many more "what if" scenarios is greatly enhanced.

Several sites along the Mississippi River and Illinois Waterway have been considered for demonstrating the potentials for integrating remote sensing and GIS technologies with habitat assessment methodologies. These sites, all of which are scheduled for future habitat rehabilitation and enhancement actions, encompass a diversity of habitat types and resource management activities.

Lake Odessa, Iowa Demonstration Site

Lake Odessa, IA, is a 6,800-acre backwater complex that lies approximately 15 miles south of Muscatine, IA, adjacent to Mississippi River navigation

pools 17 and 18. Figure 1 provides an aerial view of the project area (note Lock & Dam 17 in upper center of the figure). The site is jointly managed by the USFWS and the Iowa Department of Natural Resources (IDNR).

Extensive rehabilitation and enhancement of this area is scheduled to occur as part of the UMRS-EMP. Planning and design efforts to date have identified various improvements to water level management capabilities and the creation of new habitat as the project's primary objectives.

The Lake Odessa HREP site was selected as a test site for investigating applications of GIS and RS to the quantification methodology due to its accessibility, magnitude, and extended implementation schedule. Accessibility was an important consideration with respect to accomplishing ground truthing requirements. Habitat projects of greater magnitude tend to have longer planning and design schedules. Also, the design schedule for this particular project was found to be compatible with that of the cooperative education student who carried out the majority of this investigation.

Methodology

The identification and importation of available digital data covering the Lake Odessa project site was the initial step in this effort. Simultaneously, those variables that would most readily lend themselves to quantification via the use of GIS and RS were selected from the appropriate field sheets.

Early on it was realized that the availability digital data covering the selected project site was limited. For this reason, efforts were focused upon image processing as a "tool" in accomplishing the WHAG habitat quantification. The imagery used was color infrared photography from the National High Altitude Photography (NHAP) program. The use of satellite imagery was considered; however, the acquisition cost could not be justified based solely upon this single purpose use. High resolution scanning of NHAP color infrared positives provided raster files which were subsequently imported into CENCR's GIS.

The following Geographic Research Analysis Suspport System (GRASS) software[1] subroutines were utilized in accomplishing the processing and analysis of the scanned aerial photography:

a. **Image Rectification**. The two scanned aerial photographs required to cover the entire project area were individually rectified. This rectification was accomplished by application of the *i.v.digit*, *i.target*, *i.points*, and *i.rectify* subroutines.

[1] GRASS is a public domain, UNIX/C-based geographical information management and analysis system developed by the U.S. Army Corps of Engineers' Construction Engineering Research Laboratory, Champaign, Illinois.

b. **Imagery Tiling**. The two rectified images were patched together to create a single coverage of the project site (Figure 1). This operation was accomplished using the *i.patch* subroutine.

c. **Primary Image Classification**. *I.cluster* and *i.maxlike* are unsupervised image classification subroutines that are used to "smooth" a raster image. *R.cats* was then applied, following limited visual interpretation of the grouped signatures derived from the cluster and maximum likelyhood routines, to reduce the total number of categories to five. These five categories would be the basis for comparison with the manual categorization and classification generated as part of the WHAG process.

d. **Secondary Image Classification**. In order to improve the interpretability of the processed image, further classificatin of the pixel signatures was carried out. This included the use of *r.combine* and *r.coin*. These subroutines further simplify the classified image, consistent with the relatively coarse land cover classifications utilized in the WHAG model(s).

e. **Sample Site Delineation**. Application of the *r.mask* subroutine allowed for quantification of only that portion of the processed image that equated to the WHAG sampling area (Figure 1, yellow circle).

f. **Report Generation**. The final step included running the *D.histogram* and *r.report* subroutines. These programs generate data summaries and graphical displays of the information contained in the final processed image.

Figure 2 is a display of the final products resulting from the above processing steps. The upper left frame shows the sample site following application of processing steps 1-5. Processing step 6 results in the histogram and report displayed in the upper right and lower left frames, repectively.

Results

Land cover within the selected sample site was classified into five categories, consistent with the WHAG model requirements. Percentages for each of these five classes were generated and subsequently compared with the manually derived values for the same sample site. A thorough, statistically valid comparison of the values has yet to be accomplished. Cursory inspection suggests that potentially significant differences exist. Possible sources of the variances between the GIS/RS generated values and those that were manually calculated will be further investigated as time and resources allow.

Conclusion

Opportunities to augment and improve the quantification of habitat by employing the use of GIS and RS technologies do exist. Values for select

variables in the WHAG model may be effectively derived by electronically processing aerial photography and analysing digital databases.

Further investigation, to include the refinement of land cover signatures and the development of additional processing subroutines, is necessary to fully utilize readily available GIS and RS tools and remotely sensed imagery and digital spatial data to accomplish habitat quantification.

Figure 1

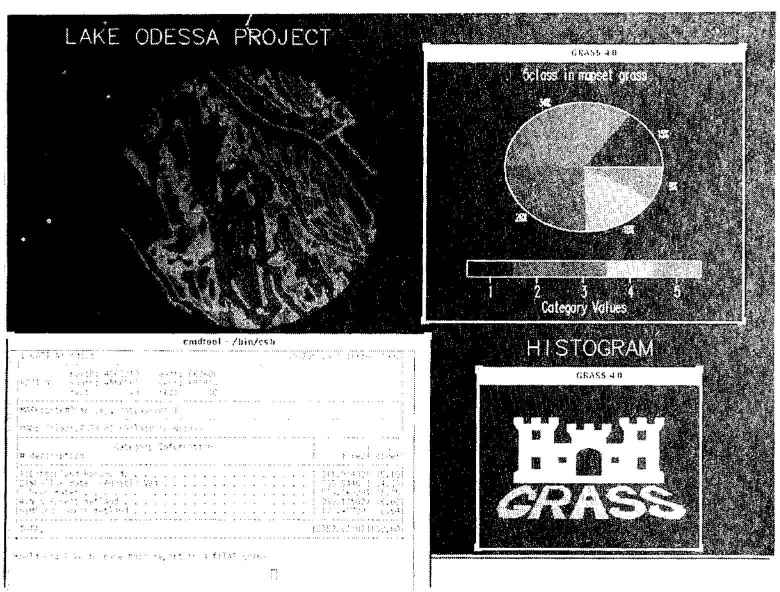

Figure 2

Inundation Tolerance of Riparian Plant Species, M. A. DeShield, Jr.[1], M. R. Reddy,[1] Steve Leonard,[2] Nasir H. Assar,[3] and William T. Brown[1]

Abstract

To determine the response of various tree and herbaceous species to different levels of flooding, a pot culture experiment was conducted. Ten different species (nine tree species and one herbaceous species: Willow oak (*Quercus phellos*), Sweetgum (*Liquidamabar styraciflua*), Bald cypress (*Taxodium disticum*), Red maple (*Acer rubrum*), Water oak (*Quercus nuttallii*), Woolgrass (*Scripus cyperinus*), Loblolly pine (*Pinus taeda*), Yellow poplar (*Liriodendron tulipifera*), River birch (*Betula nigra*), and Nuttall Oak (*Quercus nuttalli*) were screened under 0, 7, 14, and 21 days of flooding. The species were grown in 25 cm diameter pots filled with 1:1:1 sand, peat moss and top soil. The pots were flooded three times in May, July, and September of the growing season. Eight out of the ten species tested in this experiment showed normal growth and development under the 7, 14, and 21 days of flooding period. Therefore, these species appear to tolerate periodic flooding conditions and can be recommended to be used for wetland restoration. Yellow poplar did not tolerate flooding conditions and the growth and development were adversely affected. Nuttall oak did not even grow from the beginning of the experiment which could have been due to poor seedlings. The results confirm the tolerance and survival of the eight species under 21 consecutive days of flooding for 3 different inundation periods in a year.

Introduction

The understanding of flood-induced injury to plants began in the early 1990's. Early writers stressed the importance of good soil aeration and attributed injury to low oxygen concentrations in saturated condition of the soil. It is believed that both flood injury and tolerance are affected by many direct and indirect factors that interact to yield a particular set of plant characteristics (Whitlow and Harris 1979).

On the national and international levels, increasing attention drawn to wetlands has intensified the need for reliable information on the status and extent of wetland resources. In the United States, federal legislation and executive orders to protect the nation's wetland have required federal agencies to develop methods for defining, classifying, and delineating wetlands. The three federal

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[1] Department of Natural Resources and Environment Design.
[2] Division of Soil and Water Conservation, Raleigh, NC.
[3] Division of Economics, North Carolina Agricultural and Technical State University, Greensboro, NC.

regulations are from the Environmental Protection Agency, the U.S. Army Corps of Engineers, and the U.S. Fish and Wildlife Service. With assistance from other agencies such as the U.S. Soil Conservation Service, they have been developing and refining parameters to identify, classify, and delineate wetlands. The parameters are vegetation, soils, and hydrology (Parker, Fulkner, and Patrick, 1985).

North Carolina contains a large acreage of wetlands approximately 16 percent of its total land area, and silviculture operations has altered millions of acres of the state's wetlands but at the same time provided major boosts to economic development. While drainage is a fact of life for much of the State's Coastal Plain, national policy along with incentives to promote wetland conservation is requiring a second look at the conservation of wetlands to non-wetlands. This research will provide much needed information on how to proceed with riparian wetland restoration, whether it is a small tract that has been filled or hundreds of acres that have been drained for cropland.

Presently, very little information is available on the duration (consecutive days) of flooding on the survival of different plant species. Therefore, it is necessary to test the validity of the federal definition of wetlands on the wetness indicator status of plants under different hydrology and soil regimes.

Flooding a soil drastically reduces the rate of 0_2 diffusion into the soil pores and, with aerobic respiration system intact, soil oxygen is rapidly depleted (Currie 1961). Adaptations to flood tolerance fall into the broad categories, physical and metabolic. Both types of adaptations have a similar purpose, that is to decrease the effects on the plants of an anaerobic environment in the rhizosphere produced by water levels (Dubinina 1961).

In the southern United States bald cypress, swamp tupelo and water tupelo regenerate on sites that are very wet. Their best growth, however, usually occurs with moving flood water and fluctuating water levels. (Appleguist, 1960; Hook et al. 1970; Harms 1973). On the other land, Yellow poplar cannot tolerate flooding even for short durations. Although mature yellow poplars can with-stand a few days of flooding during the growing season, the seedlings of this species may be killed by two to four days of flooding, particularly if the air temperature is high (McAlpine 1959; 1961).

According to Hook and Crawford (1978) with the exception of Bald cypress conifers are generally not considered to be very flood-tolerant, however, data on conifer flood tolerance is not definitive. In comparing loblolly pine, shortleaf pine and pond pine, Hunt (1951) found no significant difference in their flood tolerance. In fact, pond pine, which grows on wet sites, appeared to be the least tolerant of the three species in height-growth and survival. Huikari (1959) found that anaerobic root media retard root growth of pine and spruce but not the growth of common birch and white birch. An interesting trait is exhibited by loblolly pine which is frequently associated with wet sites, and adaptable to a variety of sites as well. A species site test in South Carolina indicated loblolly grew well and had high survival rates on sites where the

growing season water table level averaged from 15-60 cm below the soil surface; however, a few individuals of the species survives (less than 5%) and grew well on sites where the growing season water table level stayed above the soil surface most of the time. Obviously, there are interspecific flood-tolerant traits in conifer species as well as among hardwood species.

The objective of the experiment was to test the duration of 7, 14, and 21 consecutive days of flooding on survival of plant species, or to confirm that wetland plants survive inundation of 7, 14, or 21 consecutive days.

Materials and methods

The experiment was conducted at North Carolina Agricultural and Technical State University farm in Greensboro, NC. The site is located in a lowland area adjacent to the Buffalo Creek.

Ten different plant species (nine tree species and one herbaceous species obtained from nurseries and local population in North Carolina were tested in this study. These species are abundant in wetlands throughout a large region of the Southeast and have high wildlife value and commercial timber value.

The ten different species are Willow oak (*Quercus phellos*), Sweetgum (*Liquidamabar styraciflua*), Bald cypress (*Taxodium districum*), Red maple (*Acer rubrum*), Water oak (*Quercus nuttallii*), Woolgrass(*Scripus cyperinus*), Loblolly pine (*Pinus taeda*), Yellow poplar (*Liriodendron tulipifera*), River birch (*Betula nigra*), and Nuttal oak (*Quercus nuttallii*). The treatments used in the experiment are flooding with rainwater for 7, 14, and 21 consecutive days during the growing season and control (non flooding). The experimental design was randomized complete block with five replications. A common soil mixture of sand, peat moss and top soil (1:1:1) was used. The soil mixture in the pots was maintained at a level of 15.0 cm surface to provide sufficient room for flooding which was done three times during the growing season-May, July, and September. The different species were grown in 25 cm diameter pots. A drainage spigot was installed in each plot to drain the plots after being flooded for 7, 14, and 21 consecutive and also, to drain the excess rainwater from the control plots. At the end of the growing season, dry weight of the total biomass of the plants and dy dwight of roots, stems, and leaves were recorded. Also, at the end of the experiment, careful observations were made to determine if mortality occurred. The data collected were statistically analyzed to evaluate the different treatment effects.

Results and Discussion

Analysis of variance of the biomass of the whole plants, separated leaves, stems, and roots showed the following effects: there was no significant difference in the weight of whole plant biomass, stems, and roots between the different flooding treatments. However, the weight of biomass, stems, and

roots was significantly different (P=0.01) between the species tested. The interaction between the treatments and species for the biomass stems, and roots was not significant. The weight of the leaves was significantly different (P=0.01) between the treatments and species but the interaction was not significant.

Eight species: Sweetgum, Willow Oak, Bald cypress, Red maple, Water Oak, Woolgrass, Loblolly pine, and River birch were tolerant to periodic flooding up to 21 consecutive days for three different inundation periods in a year (Table 1). Yellow poplar seedlings died within the test period, thereby confirming the known intolerance of this species to flooding. Failure of growth of Nuttall oak seedlings was probably due to poor seedlings. In an ongoing experiment, Nuttall oak seedlings are growing well. Loblolly pine, the principal commercial pine species in the southeastern states, which survived the flooding period, may be interesting to some scientific researchers, but as its name implies, it is frequently associated with wet sites, and is also well known for its adaptability to a variety of sites, abundance, and wide range.

Conclusion

The results of the experiment show that eight of the species tested can tolerate periodic flooding conditions, thus confirming the tolerance and survival of the species under 21 consecutive days of flooding. Therefore, these species can be recommended for wetland restoration.

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Table 1
The Survival of Plants after Flooding, Degree of Periodic Inundation Tolerance, and Indicator Status

Plant Species	Total Seedlings Planted	Survival of Plants after Flooding in May				Survival of Plants after Flooding in July				Survival of Plants after Flooding in September				Degree of Periodic Inundation	Indicator Status Inundation Tolerance
		7d	14d	21d	c	7c	14d	21d	c	7d	14d	21c	c		
Yellow poplar[1] (Liriodendron tulipifera)	20	--	--	--	20	--	--	--	20	--	--	--	20	Intolerant to periodic flooding	Facultative
Loblolly Pine (Pinus Theda)	20	20	20	20	20	20	16	16	20	20	16	16	20	" "	Facultative
Woodgrass (Scripus Syperinus)	20	20	18	20	15	20	19	20	15	20	19	20	15	Very tolerant to periodic flooding	Obligate
Riverbirch (Bethula nigra)	20	20	20	20	19	20	20	20	19	20	20	20	19	" "	Facultative wet
Water Oak (Quercus Nigra)	20	20	20	18	20	20	18	18	20	20	18	18	20	Moderately tolerant	Facultative
Sweetgum (Liquidambar Styraciflua)	20	19	20	18	19	19	20	18	19	19	20	18	19	Moderately tolerant to periodic flooding	Facultative
Bald cypress (Taxodium distichyum)	20	20	20	20	20	20	20	20	20	20	20	20	20	Very tolerant to periodic flooding	Obligate
Willow Oak (Quercus)	20	20	20	19	20	20	20	17	20	20	20	17	20	Moderately tolerant to periodic flooding	Facultative
Nutall Oak[2] (Quercus nutallii)	20	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Red Maple (Acerrubrum)	20	20	20	20	20	20	20	20	20	20	20	19	20	Moderately tolerant to periodic flooding	--

1 Leaves failed to recover after flooding in May. Flooding dates were May 31, July 12, and September 6, 1992.
2 Under the experimental condition, no growth occurred.

3 Concurrent Workshop Session Summaries

Session C: Design Criteria, Lawson Smith, Session Chair

Session C of the Concurrent Workshop Sessions, "Design Criteria" was held on the morning of Wednesday, 4 August, 1993, from 8:00 to 10:00. The session was chaired by Dr. Lawson Smith, WES, Principle Investigator of the "Wetland Design Criteria" work unit of the Wetlands Research Program. Ms. Samantha Breeding of FTN Associates Inc. recorded notes. Twenty-four discussants from federal agencies (62% of all discussants), state agencies (13%), universities (17%), and private industry (8%) participated in the discussions. A summary of the topics discussed is given in the following paragraphs.

At the beginning of the session, the purpose and goals of the work session were stated. The purpose of the session was to provide a forum for exchange of ideas, experiences, and knowledge between a diverse group of wetland engineers and scientists with interest and/or experience in wetland design. Two goals of the session were identified. The first goal was to obtain comments and suggestions on improving the approach of the design criteria WRP work unit. The second goal was to identify those participants who had hands on experience in designing wetlands and to obtain information from them regarding specific design criteria and it's perceived success.

In addressing the first goal of the session, a review of the underlying philosophy and concepts of the development of wetland design criteria was presented by Lawson Smith. Since there is often confusion about exactly what wetland design criteria are, the differences between design criteria and design specifications were discussed. Design criteria are instructions or guidelines for developing biological, hydrological, geological, and engineering design specifications for restoration or creation of a wetland to achieve specific wetland functions. Design specifications are detailed configurations of features such as hydraulic structures or earthwork, usually in the form of engineering drawings. The organization and research approach of the design criteria work unit was also outlined and the product and it's intended user were described.

There were a number of comments made by the session participants about the approach and the product of the design criteria work unit that were insightful and potential useful. Most of the participants felt that the design guidance should remain somewhat general, with specific guidance developed as local site conditions dictate. Designing for equilibrium between the wetland and the landscape was also considered important by most of the participants. A general consensus was reached by the group that wetland functionality changes with time and that wetland designs should be made in consideration of the functional evolution of natural "healthy" wetlands. A particularly valuable suggestion was the development of a decision matrix for designing wetlands, an idea that roughly parallels the development of "WETER". Several individuals felt that an adequate site evaluation phase should be emphasized in the preliminary design process. Finally, a participant from a sister federal agency stated that the design criteria should be offered as guidance and that we should be careful in considering them as the basis for rules that would eventually become regulatory guidance.

After approximately an hour of discussion on an approach to the development of design criteria for wetland restoration and creation projects, the subject was changed to the experiences of the participants in wetland design, especially those projects that included design, construction, management, and monitoring. Of the twenty four participants, five were willing to share their experiences with the group. A summary of their comments is given below.

Curtis Tanner, USF&WS, commented that wetland projects should begin with an attempt to clearly define the goals of the project (including selection of the functions to be provided). Then an adequate assessment should be made of the surrounding area to identify the connections between the wetland and the larger landscape system and the limiting conditions of the site. This site evaluation should focus first on hydrology, then geotechnical, and lastly vegetation. Curtis also reminded the group that it is important to conduct a site evaluation over a period of time that will define the seasonal variability of site factors.

From the Bureau of Reclamation, Eric Stiles shared his experience in restoring prairie potholes in North Dakota, primarily for the purposes of waterfowl nesting and ground water recharge. Eric mentioned that, in his experience, wetland restoration is preferred to wetland creation. Wetlands reach a state of equilibrium at some future point after restoration, therefore designs should be based on future conditions, and not necessarily present conditions. It is important to identify and separate the objectives of the project such that each can be evaluated. The repetition of similar restoration projects has resulted in the development of "rules" for prairie pothole restoration. Eric stated that he is interested in information on the restoration of prairie potholes for water quality improvement.

Nicholas Schneider, Illinois Department of Transportation, has been working on a number of mitigation banking projects in Illinois. The IDOT has been mixing research and engineering in the investigation of borrow pit

wetlands. He believes that "rules" for wetland restoration are driven more by politics than by science. In his experience, it usually is not possible to mitigate function for function. Nicholas feels that insufficient attention has been given to the geochemical characteristics of soils and ground water. He also mentioned the consideration of buffer zones between wetlands and the surrounding landscape.

Session D: Planning and Regulatory, Mary C. Landin, PhD, Session Chair

The Planning and regulatory discussion group had 56 participants (at times, standing room only). Nineteen were from the U.S. Army Corps of Engineers (USACE), and the rest were from states, other federal agencies, and private consulting businesses.

When the floor was opened for comments, participants spent the next few minutes, and periodically during the next two hours, talking about the frustration of dealing with non-technical constraints on regulatory wetlands restoration, protection, and creation (RPC). They named lack of funding, politics and policy, conflicting land uses, stovepiping within their agencies, and a variety of other constraints that have little to do with technology and engineering of wetlands.

Our group brought up 18 technical items, which we tried to relate to one or more of the series of RPC manuals WES is preparing as part of the Wetlands Research Program, and are as follows:

a. Our group's topic can best be applied to the engineering manual in Chapter 1, the early part of Chapter 2, and parts of Chapter 6 and 7, with special appendices possibilities (case studies, etc.).

b. The group provided a lot of discussion that could be used in the engineering manual as well as the design criteria, mitigation, and monitoring manuals and reports. It was noted that all of them should be broad-based, user-friendly, and suitable for technical and semi-technical (managers) audiences.

c. In Chapter 1, a section should be devoted to:

(1) Brief listing and discussion of permit needs, laws, regulations, and USACE/EPA MOA sequencing

(2) Specially funded projects such as Coastal America, Section 1135 (of WRDA 90), Breaux Act, USDA Soil Conservation Service's Conservation Reserve and Wetland Reserve programs, U.S. Fish and Wildlife Service's North American Waterflow Management Plan, and others

(3) Absolute need for the 3 C's in RPC work (coordination, communication, and cooperation)

(4) The special needs for "Mom and Pop" permit/mitigations needs

(5) Case studies that can be used even by novices for lessons learned and good examples

d. In the beginning of Chapter 1, it MUST be made very clear to any reader that any wetland RPC project being considered requires a call to the USACE District/Division Regulatory Office and the state Regulatory office.

e. It also should be made clear that internal USACE coordination is mandatory; e.g., in mitigation projects, navigation and flood control maintenance projects, and special projects involving RPC. The lack of the 3 C's can kill USACE environmental good intentions, ideas, and potential, or makes them incredibly inefficient and expensive!

f. There is a need for using a long-term management plan approach to engineering and environmental solutions to RPC.

g. When evaluating, designing, planning, constructing, etc., look beyond physical, political, and cost factors to emphasize the environmental benefits of the project.

h. Stress restoration and enhancement, with creation as a last alternative.

i. Note reasons a RPC project may be undertaken and how that can affect design, costs, construction, monitoring, and management.

j. Stress low-cost, realistic restoration technology.

k. Change the name of the manuals in the series (Mike Davis's suggestion) to a cover title, "Wetland Restoration, Protection, and Creation:" followed by a sub-title for each different manual of "Engineering," "Design Criteria," "Mitigation," "Stewardship and Management," "Monitoring and Success Criteria."

l. Discuss technical advantages/disadvantages of economy of scale; e.g., large sites vs. small sites, biodiversity and multipurpose RPC vs. specialized RPC.

m. Goals and success criteria are determined on a case-by-case, wetland type basis, and can replace regionality, so there is no point in writing regional manuals for RPC. Use wetland types to identify and discuss techniques, and that in itself will cause regionalization.

n. Manuals need a comprehensive reference section, bibliography, and perhaps a glossary.

o. Manuals need appendix source lists--equipment, geotextiles, specialty firms, state/federal offices and phone numbers, etc.

p. Make note of the problems caused by agency stovepiping that is so inefficient and costly. The delays and design problems caused by this one factor can double the cost of a RPC project, or cancel it altogether.

q. The field needs technical and engineering guidelines just for mitigation in a separate report.

r. In addition to the previous 17 items, a number of thoughts came up. The group just lists them as follows, to be sure that the thought and terminology does not escape those writing the RPC manuals:

interagency
multi-disciplinary
long-range technical team approach to RPC
low-cost designs and implementation
long-term monitoring and management
flexibility in goals and design
innovative funding
innovative technology
partnering
cost- and work-sharing
the 3 C's (over and over again)
non-technical constraints

The group also identified two local documents that may provide good information, the interagency mitigation guidelines being prepared in USACE Louisville District, and the monitoring report format for permit applicants used in USACE Chicago District.

The need for case studies to help illustrate the manuals is repeated, and two suggestions from the group were the state Departments of Transportation mitigation bank projects and the Upper Yazoo Project mitigation plan. There are numerous other possibilities from the USACE, SCS, FWS, private consultants, and states.

Session E: Monitoring and Management, Tony Dardeau, Session Chair

Discussions of the working group were on the Monitoring and Management chapter of the Wetlands Engineering Handbook. The focus was on determining the required levels of monitoring and management for all phases of

wetlands engineering projects and on documentation requirements of the handbook. The attendees of this session are categorized in groups by affiliation, as follows: two individuals from private sector, eight from the Corps of Engineers, and seven from other government agencies.

Several pertinent points were discussed by the participants. They included:

- The approach to monitoring should be based on the size and goals of the project. A large project, for example, could not be as closely monitored and managed as a project of smaller scale. Additionally, each type of wetland function chosen at a given site requires a special type of approach.

- The terms "monitoring" and "management" should be clearly defined. In general, monitoring refers to observing and measuring, while management includes those decisions and actions that are taken as a result of the monitoring effort.

- Monitoring begins with the birth of a project idea during the very early stages. It needs to be a team effort. It continues throughout the life of the project during the planning, design, construction, and post-construction phases. Those individuals involved in monitoring need to establish pre-project baseline conditions, making the necessary measurements and observations. Ground truth requirements might include monitoring wells, characterization of plant and animal life, existing habitat delineation, and photomissions.

- Research of historic records needs to be made. These records would include existing data sets, field notes, ground and aerial photography sets, and interviews with knowledgeable individuals. The reason for examining archival information is not to build a project and mitigate for historic conditions. Rather, information on change that an area has undergone may help to establish a trajectory of what can be expected even without engineering intervention.

- Once a wetlands project is constructed, the "as built," rather than the planned conditions should be used the basis for monitoring and management. Often, modifications to the original plan must be made as the project is underway. The "as built" condition will, therefore, serve as the basis for monitoring and will reflect any "tweaking" of the original plans that was necessary to complete the project. Day One would thus be the first day of operation ("as built") once construction is complete.

- The monitoring plan should also be carefully structured so that the agency and individuals responsible for project management will have a expected trajectory that spans the life of the project with intermediate checkpoints of what conditions are anticipated. Like the construction plan, the monitoring plan may also have to be "tweaked" to reflect the wetland dynamics that actually occur versus those that were predicted.

- Monitoring may consist of ground and aerial observations, observation wells, biological sampling, aerial photomissions, and soil and water analyses, which will help to determine if the expected trajectory corresponds with what is actually occurring in the field. There will probably be multiple "success" points along the trajectory because a wetland is a dynamic system.

- If the predicted trajectory does not correspond with the actual trajectory, then either "tweaking" or remedial action is necessary.

- The Corps of Engineers permit process in itself does not guarantee management to achieve desired wetland objectives over the life of a project. Five years is the maximum amount of control that a permit might have in enforcing project objectives. If the wetland creation or restoration is being constructed to satisfy some mitigation objective, then monitoring and proper management can be assured if placed in the hands of a responsible entity (e.g., state, Federal, or private conservation organization).

- Even if monitoring and management is not handed over to another agency or conservation group, these entities may be called upon to assist in monitoring (e.g., Audubon Society for bird counts). An open door policy during all stages of a project makes such groups partners and usually willing participants in the monitoring process.

- A project trajectory is often a good approximation. Success criteria should be reasonable and not too specific. For example, a bottomland hardwood stand might not be acceptable when an emergent marsh is the goal; however, degrees of success lower than expected (e.g., 300 trees/acre instead of 325 or a slightly different plant mix) might be acceptable if the success criteria are not too rigid.

- Although a difficult concept for most wetland managers, failure may be easier to define than success in terms of expected outcome at any point on the trajectory. Some results that are totally unacceptable would have to be defined as failures.

- Reference plots are useful to observe changes that would occur in a similar habitat in which engineering intervention had not taken place. These plots should be nearby and subjected to the same natural and induced pressures (e.g., natural succession, precipitation, drought, temperature extremes, invasion by exotic plant and animal species) as the project site. Thus the manager would be able to determine if changes he observed were attributable to the project or to outside influences.

- Throughout the entire monitoring and management process, common sense should prevail. Managers should be willing to observe and continually learn, making adjustments accordingly.

Session F: Hydraulics and Hydrology, Dave Richards, Session Chair

I chose to break up the session in the following categories with an equal amount of time given to each topic.

Hydrology
Hydraulics
Groundwater
Water Control Structures
Erosion Control

Attendees agreed with this approach and we were able to discuss each without a feeling that any one topic was shortchanged. None of our attendees were long-winded so the time allowed was adequate.

Hydrology

In this context we mean the classical engineering definition i.e., the flow of water overland instead of hydraulics where open channel flows are more of the concern. The following lists the key points from the discussion:

- events <u>and</u> continuous hydrologic tools needed
- frequency and depth of inundation are desired outputs
- selected hydrologic methods should be driven by project size and objectives
- develop a decision tree approach to select appropriate models
- tools are needed for developing water balances
- good sources of reference material are SCS Chapter 13 and "Wetlands.." by Grosselink
- refer reader to sources of information for running different models

In my portion of WRP, we have most of these topics well in hand. Some additional effort needs to be given to continuous hydrologic techniques. The group showed a little more interest in groundwater issues but we are putting a lot of effort in this area in the groundwater modeling research program.

Hydraulics

This is open channel flow as opposed to overland flow. Typically, the most complex hydraulic issues that need to be addressed in wetlands can be solved with 2-D models and we have made significant progress in this area.

- roughness guidance is needed that is tied to vegetation
- discuss constituent transport w.r.t nutrient removal
- discuss use of 2-D hydraulic models in wetland hydraulic design (creates velocity & w after elevation data)
- cite the need for detailed vegetation maps
- discuss sediment removal (sediment transport) models
- concentrate on physical not chemical processes
- differentiate between different hydraulic models and techniques
- give information sources for different models

Groundwater

- Refer to the SCS soil survey for first and cheapest source of information
- use soil survey classifications to determine water table variability
- look for near-by, long-term, groundwater reference stations
- consider sources of groundwater and groundwater water quality in wetland design
- develop procedures to determine seasonal variations in the water table
- give information telling when "quick and dirty" groundwater models are needed
- discuss appropriate groundwater models, cite applicability, and refer to sources to obtain user's manuals
- groundwater studies need a multi-disciplinary team approach
- USGS is a good source for groundwater field data & running USGS models

- WES is developing a comprehensive groundwater system for modeling groundwater which will be useful for wetlands

- discuss side hill seeps and levee seeps (one guy had a lot of problems out west with these wetlands)

Water control structures

Water control structures were discussed in the context that they regulate water levels in constructed wetlands. The following list the major points made.

- design requires good event <u>and</u> continuous hydrologic input

- propose using reasonable design storms (i.e., not 100 yr.)

- list structure types and applicability

- discuss maintenance issues

- discuss need to manually draw down water to combat disease, increase plant life

- maintain continuous flow through the wetland if water budget allows to minimize disease

- discuss structure construction materials (concrete, creosote, aluminum, etc.)

- discuss salinity exclusion structures (coastal Louisiana)

- suggest building structures to both control and <u>measure</u> flow (weirs, etc.)

- discuss need to allow fish migration

- instrument marshes with water level detectors if possible to allow better management of the marsh

- discuss pumping stations, siphons, diversion structures

- discuss levees

Erosion control

- SCS report #657 on grassed waterways is a good start for information

- give guidance for erosion control at outlet and inlet works
- give geotextile information
- discuss effects of wind waves, boat wakes
- discuss vegetative cover needed to eliminate erosion
- discuss slope stability (levees)
- use 2-D sediment transport models to minimize erosion

Summary

Based on the input from the group, it is apparent we need to include an H&H portion in the manual. The group identified some technology needs that have not been addressed (i.e., continuous hydrologic simulation models). We are prepared to develop some new tools, prepare TN's on their use, and to wrap up our effort by summarizing our results in the engineering manual in FY 94.

The following lists the attendees categorized in groups by affiliation at the H&H session: seven individuals from the private sector, four from the Corps of Engineers, and twelve from other government agencies.

Session G: Substrate Development, Roy Leach, Session Chair

The breakout session was attended by 18 signees and other walk-ins and was almost equally divided between engineers and biologists. The session was conducted to cover the section of the engineering handbook entitled "Engineering for Wetlands Substrate". A discussion of the subjects covered follows:

a. What should be covered in a site survey? What do we need to know? Is the site a candidate for geotechnical work? The discussion was centered on what detail was needed in information taken during the initial site survey to satisfy the biologists and also the engineers. In the handbook there should be a level of detail described that would be necessary to carry you through the level of design expected to be exercised for the site, i.e. initially looking for potential sites, elimination or selection of one site from a group, biological and engineering design of a final site. Certainly size of the project, required sampling depth, and cut or fill requirements make a difference in detail needed and site surveys should be presented that would cover small or large sites and would give detail addressing perceived design parameters.

A method should be presented to match functions with available sites found in site surveys. A discussion of functions vs sites asks which is more important, a rigid set of required functions or a site that will provide a portion of the functions? The group agreed that a team approach is certainly a must for a smooth transition from functions to site design.

b. Define substrate in the context of soils handling at the selected site? Should the section in the handbook be titled "Engineering for Wetlands Soils Handling?" A particular mining site consisting of a barren sand that has to be turned back to a wetland started a discussion on designing substrate. Is the stored sand the substrate, or is it a layer of mixed or manufactured soil added to the surface (root or growth zone) and what is being engineered under this section of the handbook?

Dr. Spigolon, under contract to write computer programs that carry the "designer" through the construction process, feels that definitions should be standardized by this handbook. Some of his thoughts were:

"....... I feel definitions are important if several diverse disciplines are going to use the same document. Some definitions that are badly needed involve the term Substrate. The following comments are offered:

(1) Substrate has been defined by several biological sciences people (Mary Landin and several others) as "the zone of root support" or "the zone that supports plant growth" or similar definitions. This definition has no meaningful counterpart in geotechnical engineering or soil science or agronomy. Even "topsoil" does not quite qualify. I suggest the term substrate be carefully defined by the users of the term and then used only in that restricted sense.

(2) Another term that has been used is subgrade. This too should not be used. In most earthwork, such as for highways or airfields, this is the material below the "grade" or surface elevation to which the site has been designed and then modified, or graded. The structure (base course and pavement) is on top of the subgrade. I do not believe this term is appropriate for a wetland.

(3) I propose that the term soil profile be used as a general term throughout the handbook instead of substrate. This term has the blessings of both the U.S. Department of Agriculture Soil Conservation Service (SCS) and of the geotechnical engineering profession. Because much of the preexisting information about the soil profile will come from SCS soil survey reports, and the SCS may be involved directly or indirectly, we should use terminology that is used by the SCS. The soil scientist's pedological terminology is also described in many geotechnical engineering textbooks. Three examples are: Chapter 2 from Spangler, M. G. and Handy, R. L, (1982). Soil Engineering, Fourth Edition, the PCA Soil Primer and the AASHTO 1988 Manual on Subsurface Investigations.

(4) I believe that the proposed handbook section on "Engineering for Wetlands Substrate" really involves soil handling, or the more used and understood geotechnical term: earthwork (excavation, transport, and fill). Therefore, I suggest the handbook section be re-designated "Engineering for Wetlands Earthwork" or "Engineering for Wetlands Soils Handling."

(5) The "substrate" is merely the upper part of the soil profile, the part that supports plant growth. If it becomes necessary to manufacture or to modify the existing or proposed substrate, that is a special soils handling job. The design of the mixture must be the responsibility of the biologists--soil scientists--agronomists--etc. The equipment and methods for doing the physical work should involve geotechnical engineers--constructors. Where this section belongs in the Handbook must be determined by your staff."

The preceding discussion seems to incorporate the definitions that are currently being used for substrate (root zone, growth zone) with the substrate being the top layer of the soil profile (all defined soil layers) including spoils from other soil handling projects. If the substrate was to be a manufactured or mixed soil from a borrow area, the borrow area would have a soil profile from which a substrate would be developed. Engineering of the wetland substrate would be the responsibility of the biologists and should be a separate section not to be confused with soils handling.

c. There was concern that soil chemistry was not being considered as part of the site surveys and soils handling techniques. Soil chemistry should be considered to define site characteristics but emphasis should also be put on changes occurring due to soil handling and placement techniques.

d. Two general themes discussed were: 1. Try not to write this handbook where it will be the only design option, "the Bible", that would be held over the owner or designer by regulators or through mitigation. Lead the designer through a design but allow room for ideas, and 2. Stress that the design should encompass a design team (engineers and biologists) from the very early stages to avoid obvious pitfalls.

Session H: Vegetation Establishment, Dr. Mary M. Davis, Session Chair

The objective of this session was to (1) get feedback on the expanded vegetation engineering outline and plant species information from people with experience in establishing wetland vegetation, (2) discuss practical issues involved with development of the wetlands engineering manual, and (3) solicit information sources for wetland restoration techniques. Due to limited time, participants were asked to comment by mail on the expanded outline. The

following summarizes discussions in response to questions posed by the chair-person.

Manual organization

The users of the Wetland Engineering Handbook are regulatory personnel, planners, and land managers. They represent a broad range in plant establishment expertise and will need to apply the information in wetland projects across the country.

Level of manual detail

The manual must be simple and user friendly for users without a strong plant background, yet detail should be maintained. Diagrams, pictures, and tables should be used liberally. Since many of the techniques do not lend themselves to a "cookbook" approach, the manual should include guidance about alternative techniques such as their cost and where they should be used.

Regional considerations

Discussion of regional problems in restoring wetlands and plant species specific information must be included in the manual. Hydrogeomorphic classifications (i.e., fringe, depressional, and riparian) will be adequate for breakdowns of regional wetland types. Regional plant species information will help increase species diversity in wetland projects and improve plant handling and management.

Cross-referencing

Wetland restoration is a multi-disciplinary effort. All portions of the manuals, including design criteria, hydraulic, sediment, and vegetation, need to be cross-referenced. Decisions made in different phases of the project are likely to impact decisions made about vegetation, and vice versa. For example, vegetation design and management will depend on whether a water control structure is designed for passive or long-term maintenance.

Plant materials

Demand for wetland plant material and experience with handling wetland plants in large quantities is helping to lower costs and increase availability of plants for restoration projects. There is, however, a need for more species-specific information on a regional basis. Specific guidance is needed for designing plantings, site preparation, use of nurse plantings, planting methods, plant handling/management, and plant sources.

Other topics

Diversity

Planting a diversity of plant material was discussed at some length. The cost/benefit ratio of obtaining diverse vegetation was questioned. If conditions are created in which herbaceous vegetation is going to succeed to woody species, the question was raised as to the value of establishing expensive diverse vegetation that is only going to be lost. In some states, regulations discourage attempts to plant a variety of species. Diversity should be a relative term used in comparison with the diversity of natural wetlands local to the project site. Planting techniques should be specified to help obtain plant diversity.

Cost estimates

Factors necessary to estimate planting costs should be discussed in the manual. Specific equations are not useful because they would not apply to project-specific conditions.

Contract specifications

Guidance provided in the manual is useful only if it can be implemented. Since much of the work is contracted out, it is necessary to be able to clearly state contract specifications for all phases of wetlands vegetation establishment. Guidance on developing contract specifications should be included in the manual.

Control of nuisance species

Many questions arose during the course of the breakout session and workshop about control methods for nuisance species. These should include mechanical, biological, and chemical methods. In addition, a discussion of what constitutes exotic species would be valuable.

Session I: General Interest, J. Craig Fischenich, Session Chair

Abstract

This paper presents a summary of comments made during the General Interest Workshop Session held on 4 August 1993 as part of the National Wetlands Engineering Workshop. Attendees of the session discussed a broad

range of issues including the handbook scope, technical content, and project implementation.

Background

Seven concurrent workshop sessions were held on 4 August 1993 as part of the National Wetlands Engineering Workshop. The purpose of the concurrent workshop sessions was to discuss the scope and content of the proposed Wetland Engineering Handbook (Handbook) to be developed under the WRP. Specific objectives of the sessions included the refinement of portions of the Handbook outline including its scope and to identify information, criteria, guidelines, etc. that should be included in the Handbook. Individual sessions were held to address design criteria, planning and regulation, monitoring and management, hydraulics and hydrology, substrate development, vegetation establishment, and general interest. This paper presents a summary of the General Interest Workshop Session.

Participants

Thirty people signed the attendee list for the session and several people participated in portions of the discussion, but did not sign the list. Those who signed represented 5 federal agencies, 4 states, 3 academic institutions, 7 consulting firms and 2 environmental interest groups. Within the USACE, there was representation from 5 districts and the WES.

Discussion

Unlike the other sessions, the General Interest Session was not constrained in the scope of topics that could be discussed. Therefore, a broad range of issues were discussed by the group over the course of two hours. Considerable attention and discussion was given to issues related to implementation. Participants expressed a general sense of frustration over their inability to implement wetland projects even with sound engineering and science backing. Much of the implementation issue revolves around land acquisition and the inability to acquire acceptable sites for projects. Recommendations for expansion of the scope to address these issues were submitted.

Attendees of the session expressed the need for a handbook that is comprehensive in scope, but concise and easy to use. The need to develop the handbook in full recognition of other non-engineering issues such as regulatory concerns, land acquisition and flexibility during construction was discussed. Utilization of figures, tables and examples was encouraged.

Major points

Following is a summary of some of the major points addressed in the session. The points are presented in no order of significance and merely highlight the topics discussed.

- Handbook Scope
  - The handbook should address coastal wetlands (Chapter 13 does not).
  - The handbook should address small wetlands.
  - Examples, photos, figures and graphs should be used when possible.
  - Function conventions used in Chapter 13 should be adopted.

- Planning
  - Function values should be expressed in economic terms.
  - Function compatibility/incompatibility should be presented.
  - The importance of aesthetics should be emphasized.

- Site Selection
  - Site selection is a critical element of most wetland projects.
  - Relative comparison techniques for sites should be presented.

- Design
  - Data sources and acquisition techniques should be addressed.
  - Mechanisms to design for extreme events must be identified.
  - Channelization and watershed development impacts should be addressed.

- Hydrology
  - The critical nature of hydrology requires that the handbook address requisite levels of study in great detail.

- Implementation Issues
  - Land acquisition issues including condemnation and lease rights should be addressed.
  - The role of partnerships in expediting implementation should be discussed.

- Construction Issues
  - Strategies to promote flexibility during construction must be presented.
  - Quality control issues and requirements need to be specified in the handbook.
  - Site-based construction planning should be emphasized.

- Monitoring & Maintenance
  - Weed and insect control strategies should be addressed.
  - Procedures and features to exploit educational benefits should be identified.

- Other
  - Terminology should be consistent and a glossary must be presented.

- The recommended approaches should correlate to regulatory requirements.
- "In-kind mitigation" needs to be addressed.
- Development trends and land use issues should be presented.
- Design approaches using a "comparison standard" should be discussed.

Summary

In general, the attendees of the session expressed the need for a handbook that is comprehensive in scope, but concise and easy to use. Attendees indicated approval of the scope of the document as defined on the draft outline that was submitted as part of the workshop material. They stressed that the handbook should recognize non-engineering issues such as regulatory concerns, land acquisition and flexibility during construction. Discussion of issues related to implementation of wetlands projects is as important to the user community as is the technical information that will be presented in the handbook.

Appendix A
Workshop Announcement

US Army Corps
of Engineers

ENGINEERING FOR WETLANDS RESTORATION:

A NATIONAL WORKSHOP

SPONSORED BY:

U.S. Army Engineer Waterways Experiment Station in cooperation with St. Louis District, Corps of Engineers

WORKSHOP OBJECTIVES

Under its Wetlands Research Program (WRP), the U.S. Army Corps of Engineers is developing improved methods for wetlands restoration and establishment. Wetlands Engineering is emerging as a new and vital aspect of these efforts.

The objective of this national workshop is to provide a forum for exchange of information on engineering techniques for wetlands restoration/enhancement projects.

TOPICS TO BE COVERED

- Planning and design approaches for wetlands establishment/restoration; site selection and assessment; design sequencing; design criteria; computerized tools and expert systems;
- Wetlands substrate design and construction; elevation and grading requirements; engineering properties of wetland soils; soils transportation and handling techniques; equipment selection; retaining structures; erosion and consolidation processes;
- Wetlands hydrology and hydraulic design; simplified techniques; rainfall-runoff and surface and groundwater flow models; water control structures; erosion control measures;
- Vegetative techniques; site preparation; selection of species; sources of plant materials; planting techniques and equipment; schedules.
- NOTE: The workshop is NOT intended to emphasize topics solely related to wetlands delineation, ecology, functions and values, etc.

FORMAT

The workshop will include presentations, displays, and panel discussions by experts on a selection of topics related to wetlands engineering. A working session will be dedicated to obtaining input from workshop participants on the content of a *Wetlands Engineering Handbook* to be published by the Corps as a part of the WRP. A field trip is also planned for the Riverlands project, a prime example of wetlands establishment associated with a major Civil Works project. Papers presented at the workshop will be published in a proceedings.

WHO SHOULD ATTEND

Engineers and scientists interested in wetlands engineering from Federal, State, and Regional/Local agencies, academia, and private consultants and contractors.

LOCATION AND ACCOMMODATIONS

The workshop will be held Tuesday, August 3, through Thursday, August 5, 1993 at the Adams Mark Hotel, St. Louis, MO. A block of rooms is reserved at the Adams Mark for the "National Wetlands Engineering Workshop" beginning the night of August 2, 1993. Rates for Federal and State government participants, including tax, will be at the

Federal Government per diem rate. Rates for non-government participants will be $88 single and $98 double, plus tax. Participants may call for room reservations at 314-241-7400. Conference attendance may be limited, so early registration is recommended.

TIMETABLE

Submit preregistration forms by April 1, 1993.

Submit abstracts for papers with preregistration by April 1, 1993.

Final program schedule and details will be mailed by May 15, 1993.

Rooms will be held at the above rates at the Adams Mark Hotel until July 2, 1993.

Workshop held August 3 to August 5, 1993.

For additional information call:
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PREREGISTRATION FORMS AND ABSTRACTS MAY BE SENT TO:

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PREREGISTRATION FORM

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☐ Register me for the National Wetlands Engineering Workshop.

☐ I have included an abstract for consideration entitled:

PRINTED ON RECYCLED PAPER

Appendix B
Workshop Agenda

AGENDA

NATIONAL WETLANDS ENGINEERING WORKSHOP

Sponsored by US Army Engineer Waterways Experiment Station (WES)
in cooperation with St. Louis District, US Army Corps of Engineers

2-5 August 1993, Adam's Mark Hotel, St. Louis, MO

Monday, 2 August 1993

7:00-9:00 Evening Registration and Get-Acquainted Social

Tuesday, 3 August 1993

8:00-5:00 Registration

Session A: Opening Plenary Session, Promenade A, B, & C
Michael R. Palermo, WES, Session Chair

8:00-8:05 Welcome - Col. James D. Craig, Commander, St. Louis District

8:05-8:15 Purpose of Workshop - Michael R. Palermo, WES

8:15-8:25 Headquarters, US Army Corps of Engineers (HQUSACE), Perspective - William E. Roper, HQUSACE, Washington, DC

8:25-8:35 Overview, Wetlands Research Program - Russell F. Theriot, WES

8:35-8:55 Role of Technology and Engineering in Wetland Restoration and Creation - Mary C. Landin, WES

8:55-9:15 National Interagency Initiative to Standardize Mitigation Procedures in Wetlands Restoration - Mike Davis, Office, Assistant Secretary of the Army (Civil Works), Washington, DC

9:15-9:35 Planning for Wetlands Water Quality - Eric A. Stiles, USBR, Denver, CO

9:35-9:55 Wetlands Restoration Is Included in Management Measures for New Coastal NPS Programs - Christopher F. Zabawa, EPA, Washington, DC, and John N. Hochheimer, Tetra Tech, Fairfax, VA

9:55-10:15 SCS Wetland Restoration and Creation from the National Viewpoint - Donald Woodward, SCS, Washington, DC

10:15-10:40 **BREAK**

Tuesday, 3 August 1993

Session A Continued

10:40-11:00 Engineering Field Handbook, Chapter 13: Wetland Restoration, Enhancement, or Creation - Wayne R. Talbot, SCS, Baton Rouge, LA, and Ronald W. Tuttle, SCS, Washington, DC

11:00-11:20 Wetland Engineering: Current Practice and Research Needs - Donald F. Hayes, University of Nebraska - Lincoln, Omaha, NE

11:20-11:40 Development of Conceptual Design Criteria for Wetlands Restoration - Lawson M. Smith, WES

11:40-12:00 Development of US Army Corps of Engineers' (USACE) Guidance for Wetlands Engineering - Michael R. Palermo, WES

12:00-1:00 **LUNCH**

Session B: Plenary Session - Case Studies; Promenade A, B, & C
E. A. (Tony) Dardeau, Jr., WES, Session Chair

1:00-1:10 Introduction to Case Studies - E. A. Dardeau, Jr., WES

1:10-1:30 Wetland Creation and Restoration Handbook - Robert E. Holman, and Wesley Childres, North Carolina State University, Raleigh, NC

1:30-1:50 Engineering of LaBranche Wetlands Restoration Project, St. Charles Parish, Louisiana - Richard W. Broussard, Jr., and Edwin M. Dickson, Jr., New Orleans District

1:50-2:10 Intertidal Habitat Restoration in an Urban Environment: The Federal Center South Coastal America Project - Patrick Cagney, Seattle District; Curtis Tanner, USFWS, Olympia, WA

2:10-2:30 Environmental Engineering and Wetland Mitigation: The Upper Yazoo Projects - E. A. Dardeau, Jr., and J. Craig Fischenich, WES, Gary L. Young, Vicksburg District

2:30-3:00 **BREAK**

3:00-3:20 Use of Multiple Options for Establishing Wetland Hydrology: The Manasquan Reservoir Project - Ray Hinkle, Woodward-Clyde Consultants, Wayne, NJ

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Tuesday, 3 August 1993

Session B Continued

3:20-3:40 United States National Marine Fisheries Service Role/Contribution in Restoring Coastal Habitats in Louisiana - Timothy Osborn and Erik Zorbrist, NOAA/NMFS, Silver Spring, MD

3:40-4:00 Kawaiuni Marsh Restoration - James Pennaz and Margo Stahl, Honolulu District

4:00-4:20 Design, Construction, and Monitoring of a Created Wetland at the University of Colorado Research Park, Boulder - Lauranne P. Rink, Aquatic and Wetland Consultants, Inc., Boulder, CO, and John T. Windell, Professor Emeritus, University of Colorado, Boulder, CO

4:20-4:30 Purpose of Workshop Sessions - Michael R. Palermo, WES

Wednesday, 4 August 1993

8:00-5:00 Registration

8:00-10:00 **Concurrent Workshop Sessions (Review and Discussion of Wetlands Engineering Handbook)**

Session C: Design Criteria, Director's Row 23

Session D: Planning and Regulatory, Director's Row 24

Session E: Monitoring and Management, Director's Row 25

Session F: Hydraulics and Hydrology, Director's Row 26

Session G: Substrate Development, Director's Row 27

Session H: Vegetation Establishment, Director's Row 28

Session I: General Interest, Director's Row 29

10:00-10:30 **BREAK**

Wednesday, 4 August 1993

10:30-4:30 **Concurrent Technical Sessions J/K (Promenade A) and L (Promenade B)**

Session J: Site Selection; Promenade A
J. Craig Fischenich, WES, Session Chair

10:30-10:40 Introduction to Site Selection - J. Craig Fischenich, WES

10:40-11:00 Wetlands Hydrology Assessment for Siting and Design - J. Craig Fischenich, WES, Scott Franklin, Omaha District, and E. A. Dardeau, Jr., WES

11:00-11:20 St. Clair County Wetland Mitigaion Bank - Mark Ray, Woolpert, Dayton, OH

11:20-11:40 Wetlands Restoration Planning Tool - John N. Hochheimer, Mohammed Lahlou, and Chris Rodstrom, Tetra Tech, Inc., Fairfax, VA

11:40-12:00 Orwell Lake Wetland Restoration Under the Section 1135 Program - Peter J. Fasbender, St. Paul District

12:00-1:00 **LUNCH**

Session K: Design Criteria; Promenade A
Lawson M. Smith, WES, Session Chair

1:00-1:20 Introduction to Design Criteria, Lawson M. Smith, WES

1:20-1:40 Wetland Establishment Software System - Samantha Breeding, FTN Associates, and Jerry L. Miller, WES

1:40-2:00 Taking the Bite Out of Wetland Mosquito Problems - Jerry Lang and Mark Ray, Woolpert, Dayton, OH

2:00-2:20 Criteria for Wetland Restoration Site Selections; Case Studies in Elliott and Commencement Bays in Puget Sound, Washington - Robert C. Clark, Jr., NOAA/NMFS, Seattle, WA

2:20-2:40 Ecological Engineering Considerations in Constructing Wetlands for Surface Mine Reclamation - Robert B. Atkinson, David H. Jones, and John Cairns, Jr., Virginia Polytechnic Institute and State University, Blacksburg, VA

2:40-3:00 **BREAK**

Wednesday, 4 August 1993

Session L: Substrate Design; Promenade B
Roy E. Leach, WES, Session Chair

10:30-10:40 Introduction to Substrate Design - Roy E. Leach, WES

10:40-11:00 Engineering Description and Collection of Wetland Soil Properties - Lawrence D. Johnson and Roy E. Leach, WES

11:00-11:20 Sediment Diversion Projects, Plaquemines Parish, Louisiana - R. Steve Fox, New Orleans District

11:20-11:40 Low-Impact Restoration of a Forested Wetland, Upland, and Stream Corridor Site in Southern Maine - David P. Cowan, Normandeau Associates, Inc., Yarmouth, ME

11:40-12:00 Soils and Site Selection in Wetland Construction - Mallory N. Gilbert, Private Consultant, State College, PA

12:00-1:00 **LUNCH**

1:00-1:20 GEOtechnical Factors in WETlands ENgineering (GEOWETEN): A Prototype Knowledge-Based Expert System - S. Joseph Spigolon, SJS Corporation, Coos Bay, OR and Reda M. Bakeer, Tulane University, New Orleans, LA

1:20-1:40 Lost Lake Restoration and Wetlands Mitigation Monitoring - Tanya Youngblood and H. Ornes, University of South Carolina - Aiken, Aiken, SC; H. Mackay and S. Riley, Westinghouse Savannah River Company, Aiken, SC

1:40-2:00 Constructed Wetlands for Sediment Control and Water Quality Improvement at Corps of Engineers' Reservoirs - Charles W. Downer, WES

2:00-2:20 Is Big Better? Challenges and Opportunities in Large Site Wetland Restoration - Steven A. Ott, Johnson, Johnson, and Roy, Ann Arbor, MI

2:20-3:00 **BREAK**

Plenary Workshop Session C through I Reports; Promenade A and B

3:00-4:30 Reports of the Workshop Session Chairmen

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Thursday, 5 August 1993

8:00-12:00 **Concurrent Technical Sessions M (Promenade A) and N (Promenade B)**

Session M: Hydrology and Hydraulic Design; Promenade A
David R. Richards, WES, Session Chair

8:00-8:10 Introduction to Case Studies - David R. Richards, WES

8:10-8:30 Appropriate Technology for Wetlands Hydraulic Design - Lisa C. Roig, WES

8:30-8:50 Design and Construction of a Coastal Plain Small Stream Swamp in Eastern North Carolina - Jeff Furness, Texasgulf, Inc., Aurora NC, and Ted Shear, North Carolina State University, Raleigh, NC

8:50-9:10 Hydrological Considerations Associated with Constructing Wetlands in Alluvial Soils on a 31-Acre Floodplain Site in Central Pennsylvania: A Case Study - Irwin Garskof, Baltimore District

9:10-9:30 Stoplog Weir at Grassy Lake, Louisiana: Potential for Fishery Enhancement - Jan Jeffrey Hoover, K. Jack Killgore, and Erik K. Nelson, WES, and Mark Konikoff, University of Southwestern Louisiana, Lafayette, LA

9:30-10:00 **BREAK**

10:00-10:20 Recreation of a Mature Palustrine Forested Wetland with Vernal Pools - Phillip R. Ross, and Steven M. Jones, BCM Engineers, Inc., Plymouth Meeting, PA

10:20-10:40 Stream Restoration Project Designs That Protect Wetlands - Chester A. McConnell, Wildlife Management Institute, Lawrenceburg, TN

10:40-11:00 Two-Dimensional Hydrodynamic Modeling of Wetland Surface Flows - Robert A. Evans and Lisa C. Roig, WES

11:00-11:20 Hydrology, Vegetation, and Nutrient Removal Dynamics in a Large Constructed Wetland - David L. Stites, Jonathon Polinkas, and Vickie Schwenke, St. John's River Water Management District, Palatka, FL

11:20-11:40 Stormwater Best Management Practices and Wetlands Restoration - John N. Hochheimer and Mary Beth Corrigan, Tetra Tech, Fairfax, VA, and Fran Eargle, EPA, Washington, DC

11:40-12:00 Relationships Between Plant Communities, Hydrologic Regimes, and Edaphic Factors, and Implications for Design of Swamp Restoration Projects - Ted Shear and Brian Bledsoe, North Carolina State University, Raleigh, NC

12:00-1:00 **LUNCH**

Thursday, 5 August 1993

Session N: Vegetative Techniques; Promenade B
Mary Davis, WES, Session Chair

8:00-8:10 Introduction to Vegetative Techniques - Mary M. Davis, WES

8:10-8:30 Meeting Technical Needs for Wetland Vegetation Restoration - Mary M. Davis

8:30-8:50 Bottomland Forest Reestablishment Efforts of the USFWS: Southeast Region - Ronnie J. Haynes, USFWS, Atlanta, GA, *et al.*

8:50-9:10 Bottomland Hardwood Mitigation for Reservoir Construction - D. McGrain, D.J. Frederick, and E.C. Franklin, North Carolina State University, Raleigh, NC

9:10-9:30 Specifications in Wetland Mitigation - Kenneth P. Dunne, Lewis Morgan, and Mahendra Rodrigo, Louis Berger and Associates, East Orange, NJ

9:30-10:00 **BREAK**

10:00-10:20 Wetlands Bioengineering for Erosion Control on Reservoirs - Burl D. Ragland, Tulsa District; Hollis H. Allen, WES; John H. Brigham and Michel D. Dunford, Tulsa District

10:20-10:40 Plantation Establishment to Restore Bottomland Hardwood Wetlands: Past and Future Research at the Southern Hardwoods Laboratory - John A. Stanturf, US Forest Service, Stoneville, MS

10:40-11:00 Selection and Evaluation of Plant Materials for Constructed Wetlands - Donald Surrency, SCS, Athens, GA

11:00-11:20 A Paradigm for the Selection of Vegetation Effective in Phosphorus Removal for Restored and Created Wetlands - Lynn E. Zender, University of California - Davis, Davis, CA

11:20-11:40 Geographic Information System and Remote Sensing Applications in Habitat Quantification Methodologies: The Wildlife Habitat Appraisal Guide - Jerry Skalak and Joe Jordan, Rock Island District

11:40-12:00 Inundation Tolerance of Riparian Wetland Species - McKinley A. DeShield, Jr., M. R. Reddy, Steve Leonard, and William T. Brown, North Carolina A&T State University, Greensboro, NC

12:00-1:00 **LUNCH**

1:00-4:30 **Riverlands Field Trip** (If the field trip is cancelled due to flooding at the site, the Riverlands staff have been invited to give a presentation which will be held in the St. Louis Ballroom E.)

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Appendix C
Lists of Participants and Authors and Session Chairs

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St. Louis, Missouri 2 - 5 August 1993

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* U.S. GOVERNMENT PRINTING OFFICE: 1995-633-144/00007

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	March 1995	Final report

4. TITLE AND SUBTITLE
Proceedings: National Wetlands Engineering Workshop; St. Louis, Missouri, 3 - 5 August 1993

5. FUNDING NUMBERS
Work Unit 32760

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8. PERFORMING ORGANIZATION REPORT NUMBER
Technical Report WRP-RE-8

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
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10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

A National Wetlands Engineering Workshop was held in St. Louis, MO, on 3-5 August 1993. The purpose of the workshop was to provide a forum for an exchange of information on engineering techniques for wetlands restoration/enhancement projects. Over 50 papers were presented by engineers and scientists from the Federal government, private consulting firms, and academia and are contained in the proceedings. All papers presented at the workshop are published in this report. Breakout sessions dedicated to obtaining input from workshop participants on the content of a Wetlands Engineering Handbook were also held. Summaries of these sessions are also included in the proceedings report.

14. SUBJECT TERMS
Creation | Restoration | Wetlands engineering

15. NUMBER OF PAGES
450

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED		

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102